EngrTEAMS

EngrTEAMS: Engineering to Transform the Education of Analysis, Measurement, and Science in a Team-Based Targeted Mathematics-Science Partnership

Pollutants in the Pond

Grades 4-5

University of Minnesota
STEM Education Center
NSF
INSPIRE Research Institute for Pre-College Engineering
Purdue University

This material is based upon work supported by the National Science Foundation under grant NSF DRL-1238140. 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.

Acknowledgments

Authors
Teacher Fellow Lead Authors: Sean Duncanson, Teresa Stevens, Drew Houland
Project Authors: Richard Lie, Corey Mathis, Angelina Constantine, Christina Miller, Tamara Moore, Kerrie Douglas

Leadership
Principal Investigator: Tamara Moore
Co-Principle Investigators: Paul Imbertson, Marshall Davis, Selcen Guzey, Gillian Roehrig

Management
Project Director: Cynthia Stevenson
Event Assistant: Barbara Wojcik
Research Coordinator: Aran Glancy

Technical Assistance
ECSU/GRO: Julie Frame
ECSU/GRO: Jean Jordan
ECSU/GRO: Jane Holmberg

School District Partners
South Washington County: Emily Larsen
Saint Paul: Molly Leifeld, Marshall Davis
North St. Paul: Penny Baker
Minneapolis: Elizabeth Stretch, Charlene Ellingson

Evaluation
Evaluator: Jane Fields

Curriculum Editors
Emily Haluschak, Samantha Miller, Tamara Moore, Aran Glancy

About EngrTEAMS

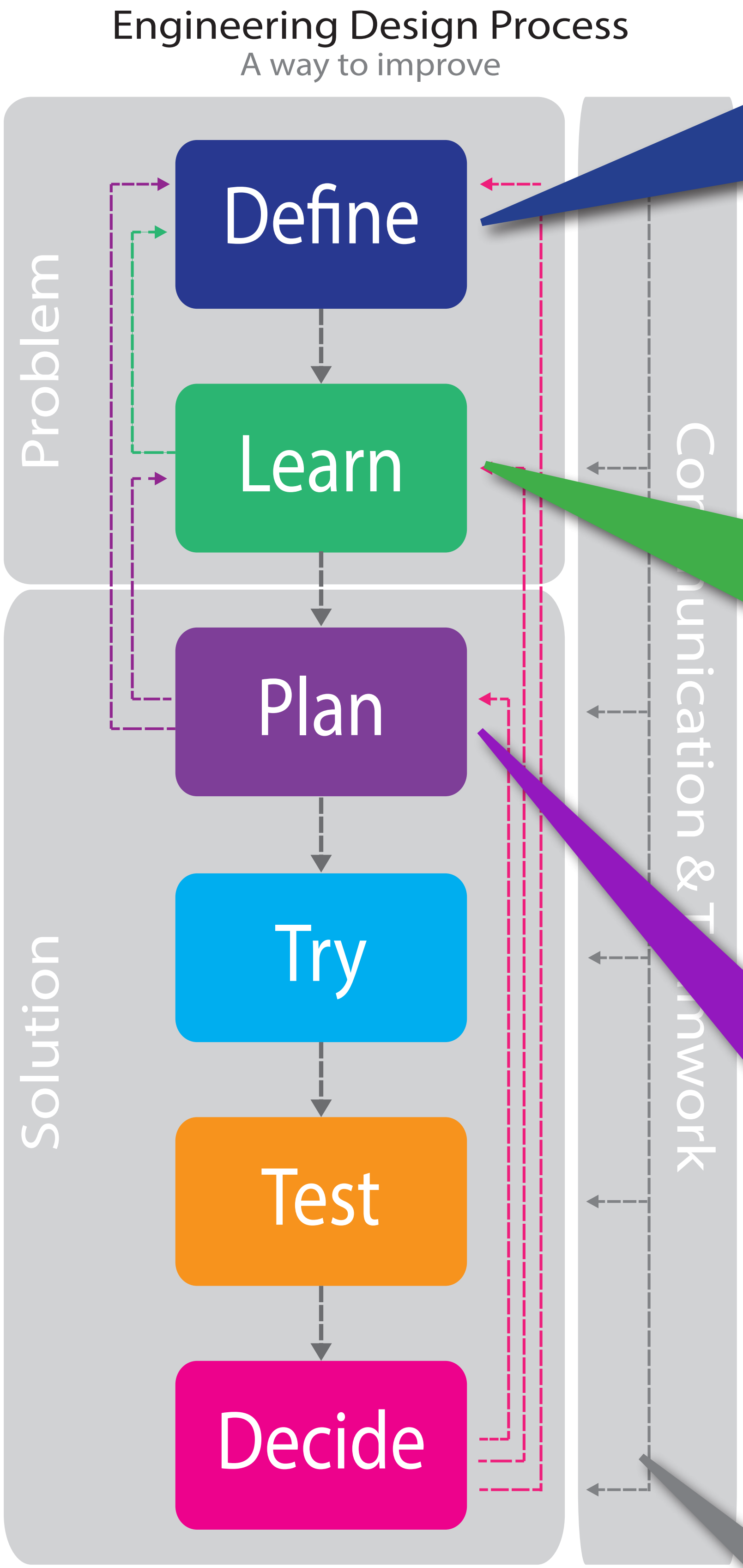
Purpose

The project is designed to help 200+ teachers develop engineering design-based curricular units for each of the major science topic areas within the Next Generation Science Standards, as well as data analysis and measurement standards for grades 4-8.

With a focus on vertical alignment and transition from upper elementary to middle-level, this project will impact at least 15,000 students over the life of the grant.

To learn more about the project and find additional curricular units go to www.engrteams.org.

Overview: Engineering Design Process



DEFINE THE PROBLEM

- Who is the **client**?
- What does the client need?
- Why does the client need it?
- Who is the **end user**?
- Why might the end user want it?
- What are the **criteria** (requirements) and **constraints** (limits) of the solution?

Problem Scoping:
WHO needs **WHAT** because **WHY**

LEARN ABOUT THE PROBLEM

- What kind of background knowledge is needed?
  - What science/math knowledge will be needed?
  - What materials will be needed?
- What has already been done to solve the problem?
- What products fill a similar need?
- How should we measure success and improvement?

PLAN A SOLUTION

- Continue to specify the criteria/ constraints
- Generate ideas of possible solutions
- Develop multiple solution paths
- Consider **constraints, criteria**, and **trade-offs** (criteria that compete with one another)
- Choose a solution to try
- Develop plans (blueprints, schematics, cost sheets, storyboards, notebook pages, etc.)

COMMUNICATION

- Communicate the solution clearly and make sure it is easily understandable
- Use **evidence** to support why the client should use your solution

Overview: Engineering Design Process

TRY A SOLUTION

- Put the plan into action
- Consider risks and how to optimize work
- Use criteria/constraints and consider trade-offs from the problem/plan to build a **prototype** (a testable representation of a solution), **model**, or **product**

TEST A SOLUTION

- Consider testable questions or hypotheses
- Develop experiments or rubrics to determine if the solution is meeting the stated criteria, constraints, and needs
- Collect and analyze data

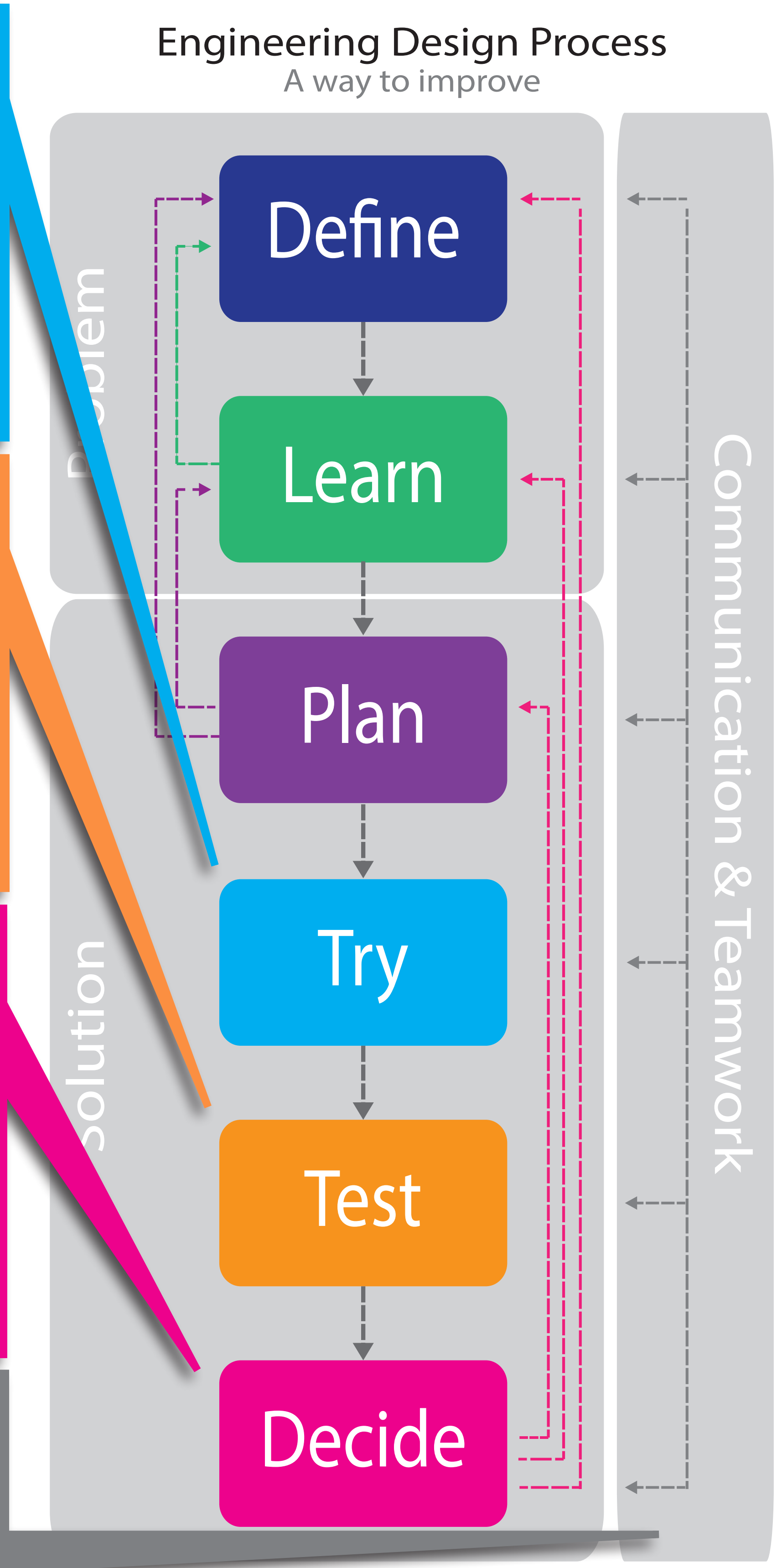
DECIDE IF THE SOLUTION IS GOOD ENOUGH

- Are users able to use the design to help with the problem?
- Does the design meet the criteria and constraints?
- How could the design be improved based on test results and feedback from the client/user?

Iterative nature of design: Always consider which step should be next!

TEAMWORK

- Discuss in teams how the solution meets the criteria and needs of the client
- Consider different viewpoints from each teammate



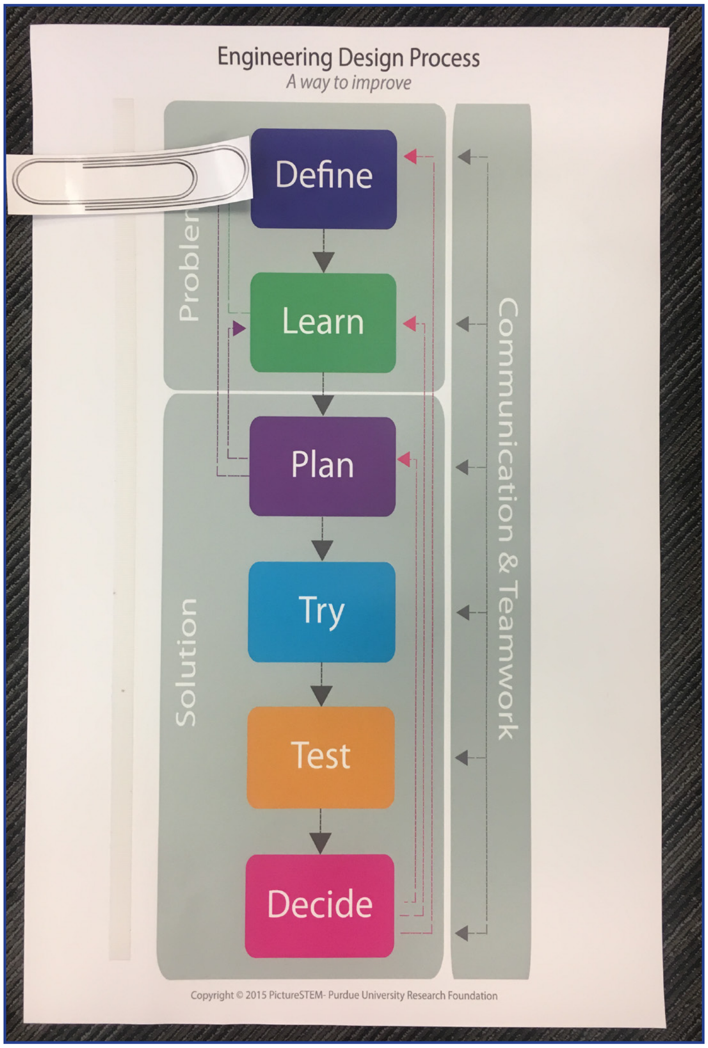
Overview: How to make EDP sliders

HOW TO CREATE THE POSTER

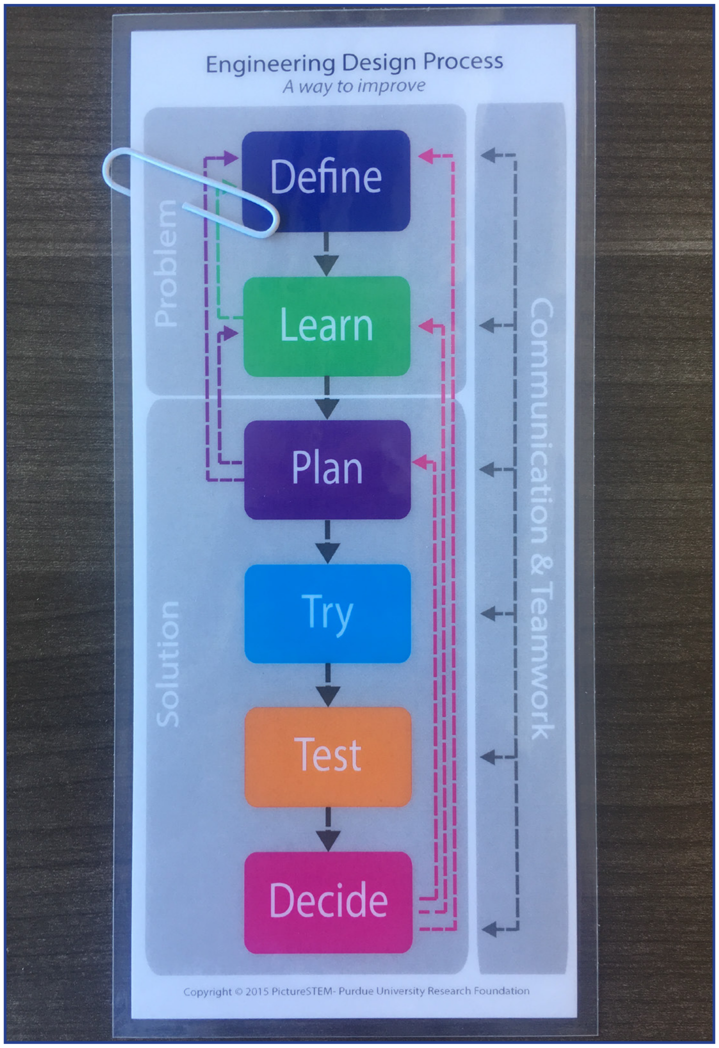
1. Download the high-quality PictureSTEM Slider Poster and the paper clip images from PictureSTEM.org.
2. Print the poster and the paper clip on poster-sized paper and cut to size. High-gloss or semi-gloss paper is the best choice.
3. Use self-sticking Velcro on the back of the paper clip and down the side of the poster so that the paper clip can be placed to point at all 6 sections of the slider.

HOW TO CREATE INDIVIDUAL SLIDERS

1. Print the sliders on the opposite page - enough for one slider per student in your class.
2. Cut the sliders apart.
3. Laminate the sliders individually.
4. Use a jumbo paper clip as the pointer for each slider.

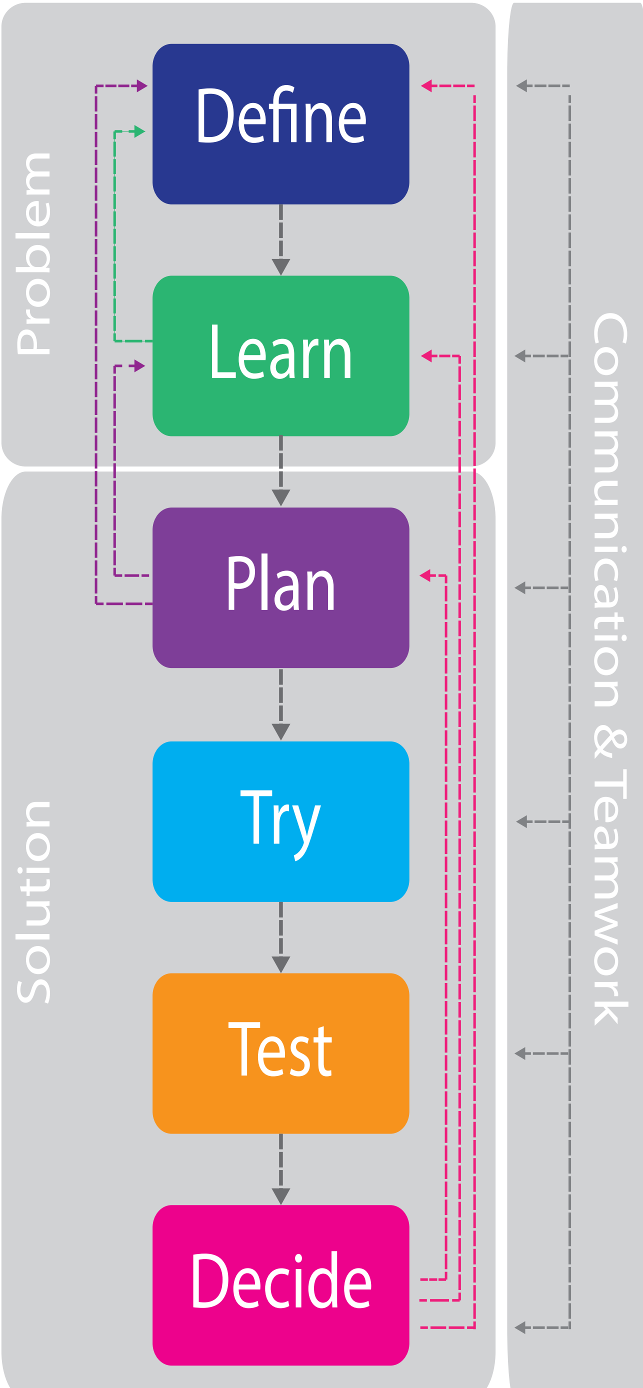


Poster

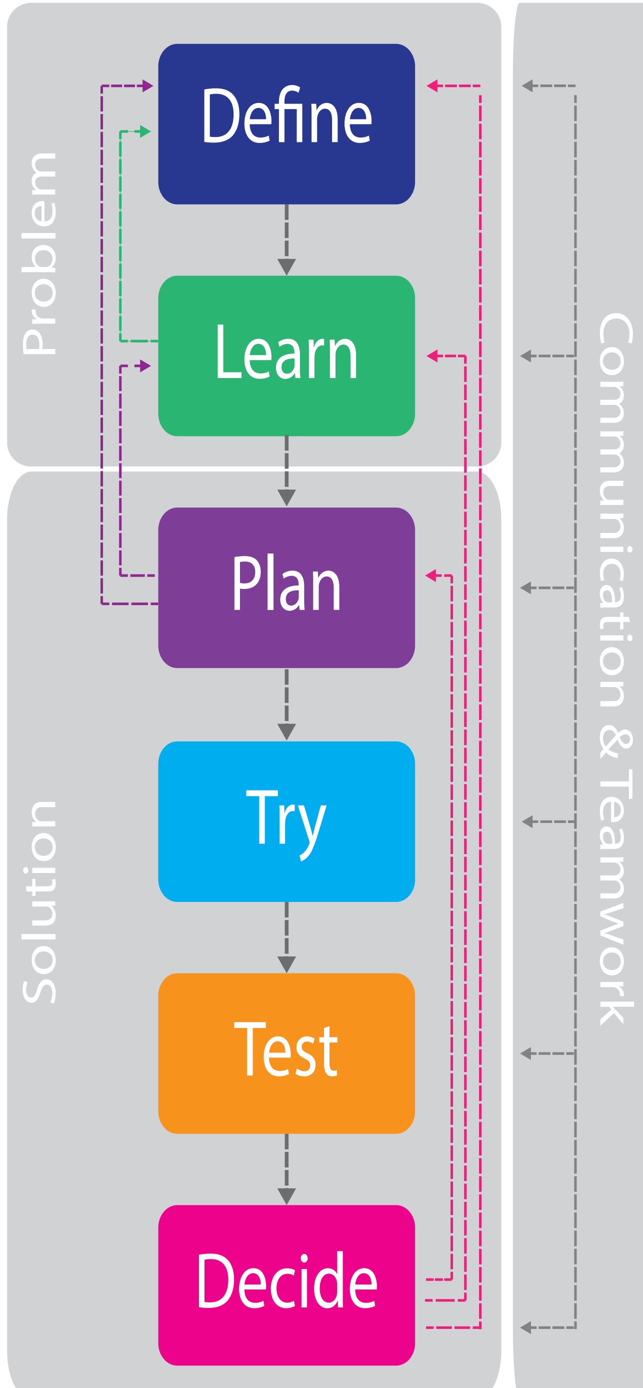


Individual slider

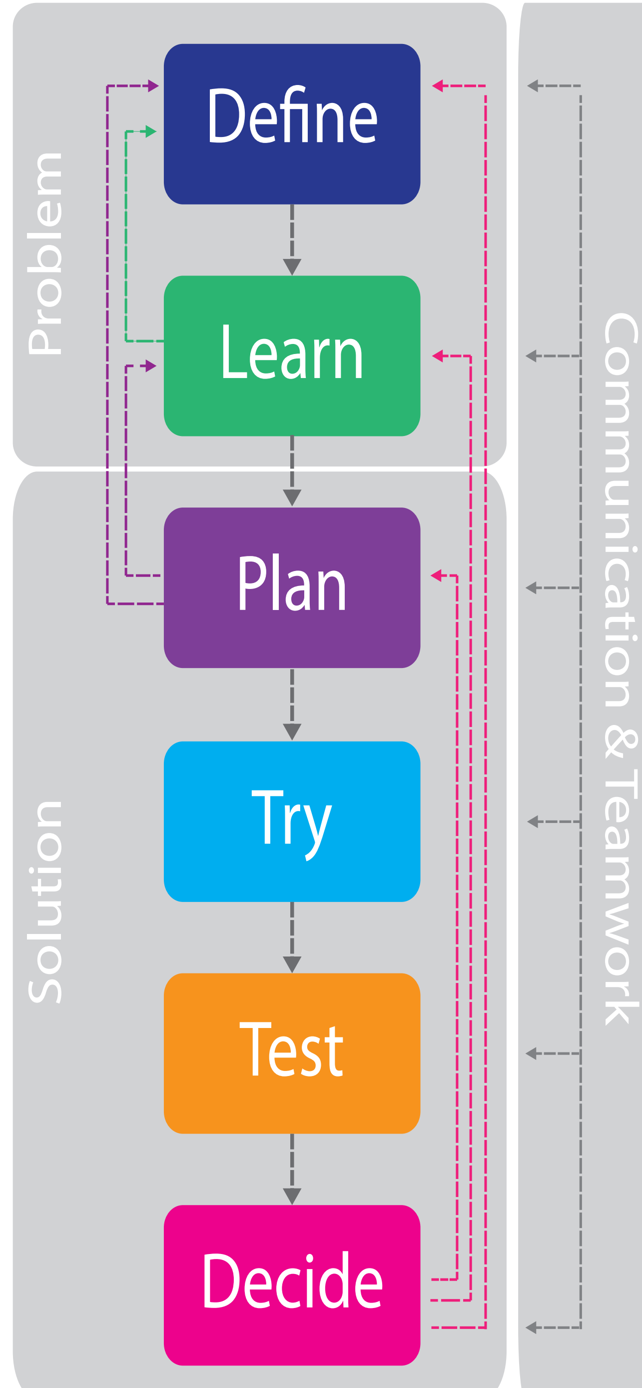
Engineering Design Process
A way to improve



Engineering Design Process
A way to improve



Engineering Design Process
A way to improve



Overview: Unit Description

Grade Level:

5

Approximate Time Needed to Complete Unit:

Thirteen 50-minute class periods

Unit Summary

Humans impact the environment in many different ways. Our impact on the environment may be unintentional, but it can greatly change the surrounding ecosystem. Students will learn how the use of fertilizer and other runoff products impact local ecosystems. Additionally, students will learn how all organisms can be impacted by pollutants through developing knowledge of food chains and the effect nitrates on pond ecosystems. Presented with the context of a local pond experiencing a decline in fish population, students will design and test solutions to prevent runoff pollution. They will connect their results back to the ecosystem and see how their solutions may help the local pond's ecosystem.

Science Connections	Technology & Engineering Connections	Mathematics Connections
food webs, ecosystems, interdependent relationships in ecosystems, pollution, environmental impact	engineering design process	collect and graph data from experiments, line plots, analyze data and make a data driven decision

Unit Standards

Next Generation Science Standards

- **5-LS1-1:** Support an argument that plants get the materials they need for growth chiefly from air and water.
- **5-LS2-1:** Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.
- **5-ESS3-1:** Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.
- **3-5-ETS1-A:** Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- **3-5-ETS1-B:** Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- **3-5-ETS1-C:** Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Common Core State Standards - Mathematics

- **MP1:** Make sense of problems and persevere in solving them.
- **MP3:** Construct viable arguments and critique the reasoning of others.
- **MP4**: Model with mathematics.
- **MP5:** Use appropriate tools strategically.
- **MP6:** Attend to precision.

- **4.MD.A.2:** Use the four operations to solve word problems involving distances, intervals of time, liquid volumes, masses of objects, and money, including problems involving simple fractions or decimals, and problems that require expressing measurements given in a larger unit in terms of a smaller unit. Represent measurement quantities using diagrams such as number line diagrams that feature a measurement scale.
- **5.G.A.2:** Represent real world and mathematical problems by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation.
- **5.NBT.A.1:** Recognize that in a multi-digit number, a digit in one place represents 10 times as much as it represents in the place to its right and 1/10 of what it represents in the place to its left.

Unit Assessment Summary

Throughout this unit, students individually maintain an engineering notebook to document their engineering design processes. In this, students make observations, collect data, and plan for their design. Part of the engineering notebook includes answering specific questions related to that day's activities. You may choose to post the questions on your overhead/PowerPoint slides, or give the students printed versions (included as duplication masters in each applicable lesson) to tape into their notebooks. Students use their notebooks as a reference – a place to maintain the information they are learning through design. Additionally, students reflect on their work throughout the design process. This is important for modeling what real-life engineers do. **Collect the engineering notebooks at the end of each class.** You will use the notebooks to assess student learning through their design process. Provide feedback to students on their notebook responses - rubrics are provided. You are encouraged to assign points for responses in the engineering notebooks. **Provide feedback often - especially lessons for which rubrics are provided.**

- The notebook pages are often set up as handouts in each lesson. If you prefer to use notebooks without having students paste copied pages in them, there is an appendix at the end of this unit that includes notebook prompts and how to have students title each entry.
- The final summative piece of this unit requires students to communicate to the client recommending a design and justifying its success as a solution to the engineering problem.

Overview: Lesson Summaries

Lesson 1: Defining the Engineering Problem

Students are introduced to the engineering challenge exploring a pond ecosystem. Students engage in problem scoping as they discuss and identify the design challenge described in a memo from the Department of Natural Resources who is requesting student engineers' help to design a solution to prevent runoff pollution that is harming the Horseshoe Pond ecosystem. Students use this information to identify the information necessary they must learn to solve the problem.

Lesson 2: Humans and the Environment

Students discuss the key components of an ecosystem. Students then work through lab stations where they examine how different amounts of fertilizer alters a pond ecosystem. Students examine the different aspects of the pond ecosystem by (1) measuring the concentration of nitrates and phosphates, (2) examining changes in plant health and algae growth, and (3) comparing the changes observed over time. Students then make connections from real-world examples and their observations to draw conclusions. The lesson concludes with students summarizing what they have learned and how this information provides insight on how they might solve the client's problem.

Lesson 3: Food Webs

In this lesson, students explore the interdependence of organisms within a community by constructing a pond food web. Using the models generated, students discuss the movement of energy through an ecosystem and participate in a gallery walk to share their models. Students use this information to make prediction about how biotic and abiotic changes in the ecosystem alter the food web. Students connect how fertilizer runoff affects the ecosystem described in the client letter.

Optional Lesson A: Guest Speaker

Students interact with a guest speaker that is involved with ecosystem balance on a regular occurrence. Students learn about the duties and responsibilities of the guest speaker and discuss how this new information fits into the context of the client problem.

Overview: Lesson Summaries

Lesson 4: Designing a Solution

Prior to planning their design, student are exposed to common strategies used to combat runoff pollution. They are then introduced to the design challenge and complete several practice problem to familiarize themselves with the model. Students individually reflect on the information they have learned about pond ecosystems and the criteria and constraints identified by the client to think about possible solutions and explore the available materials to individual create a plan. Finally, students rejoin their team to create a plan to construct a design that prevents chemicals from fertilizers from entering the pond water supply and is environmentally mindful. Students share their designs and results among the class.

Lesson 5: Redesigning a Solution

Students reflect upon their first design and then construct a new solution based on their data and observations. Students then build and retest their new design to better fit the client's criteria and constraints. After testing and calculating their results, the students use their data to justify the effectiveness of their design. Students record and share their results and consider which of their two designs best fit the client's request.

Lesson 6: Communicating with the Client

Students present their final design recommendation to the client in the form of a poster and oral presentation to the class. In the presentation, students use evidence to justify how their design met the client's criteria and constraints and connect their results to the larger picture, specifically how their design will impact the pond ecosystem.

Overview: Unit Overview

Lesson	Time Needed	Objectives The student will be able to:
1: Defining the Engineering Problem	two 50-minute class periods	• engage in problem scoping with the client letter. • develop a list of questions to ask the client.
2: Humans and the Environment	three 50-minute class periods	• describe an ecosystem. • differentiate between abiotic and biotic factors. • discuss the role of phosphates and nitrates in an aquatic ecosystem. • measure nitrate and phosphate levels. • make and record qualitative observations. • analyze graphical data.
3: Food Webs	two 50-minute class periods	• define vocabulary relevant to pond and pond ecosystems. • create a food web for a pond ecosystem. • describe how changes at one level of an ecosystem affect other related organisms.
Optional Lesson A: Guest Speaker	one 50-minute class period	• interact with a guest speaker, who is involved with ecosystem balance. • discuss findings based on guest speaker.

Overview: Unit Overview

Materials	Duplication Masters & Educator Resources
• **Per class:** (1) Engineering Design Process poster, chart paper • **Per student:** (1) pen, (1) Engineering Notebook, (1) Engineering Design Process slider and jumbo paper clip	**DUPLICATION MASTERS** • 1.a. What Do You Know About Engineers? • 1.b. Client Letter • 1.c. Questions for the Client • 1.e. Problem Scoping **EDUCATOR RESOURCES** • 1.d. List of Client Questions and Responses • 1.e. Problem Scoping - KEY • 1.f. Questions for the Client and Problem Scoping Rubric
• **Per class:** (1) Engineering Design Process poster, (27) Nitrate test strips, (27) large jars (32 oz), water (from a nearby pond or tap water), fertilizer, LaMotte phosphate test tabs (27 tabs), (27) centrifuge tubes (15 mL), aquatic plant (hornwort), 3”x5” index cards (white and multi-colored), paper towels, masking tape, chart paper • **Per team:** plastic dropper, stopwatch • **Per student:** (1) pen, (1) Engineering Notebook, (1) Engineering Design Process slider and jumbo paper clip	**DUPLICATION MASTERS** • 2.b. Video Vocabulary • 2.e. Fertilizer Experiment Packet • 2.f. Phosphate and Nitrate Direction Checklist • 2.g. Horseshoe Pond Data • 2.h. Farmer’s Letter • 2.i. Horseshoe Pond Data Analysis **EDUCATOR RESOURCES** • 2.a. Teacher Directions for Experimental Setup • 2.c. Video Vocabulary Answer Key • 2.d. Abiotic vs Biotic Anchor Chart • 2.j. Horseshoe Pond Data Analysis Answer Key
• **Per class:** (1) Engineering Design Process poster, tape • **Per team:** glue or tape, chart paper, marker • **Per student:** (1) pen, (1) Engineering Notebook, (1) Engineering Design Process slider and jumbo paper clip	**DUPLICATION MASTERS** • 3.a. Pond Organism Cards • 3.b. Organism Information Sheet • **(Optional)** 3.d. Bonus Pond Organisms **EDUCATOR RESOURCES** • 3.c. Example Food Web • **(Optional)** 3.e. Bonus Example Food Web
• **Per student:** (1) pen, (1) Engineering Notebook, (1) Engineering Design Process slider and jumbo paper clip	

Overview: Unit Overview

Lesson	Time Needed	Objectives The student will be able to:
4: Designing a Solution	three 50-minute class periods	• brainstorm methods and plan a strategy to prevent runoff pollution. • communicate design idea through drawing, including labels for materials and function of parts. • select potential solution through systematic evaluation of various solution based on the problem. • construct, test, and evaluate their design.
5: Redesigning a Solution	two 50-minute class periods	• evaluate their first prototype based on their initial testing. • redesign their solutions based on their first design. • apply science and mathematics to inform the redesign. • build and test their second prototype.
6: Communicating with the Client	one-two 50-minute periods	• collaborate and discuss their findings within their teams to report back to the client. • connect the outcomes of their testing to the impact on the environment. • communicate their solution to the client in the form of a poster and presentation. • justify why their design solution is appropriate based on science and mathematics. • justify why their design solution is appropriate based on their problem scoping. • apply evidence gathered from testing to choose solution.

Overview: Unit Overview

Materials	Duplication Masters & Educator Resources
• **Per class:** (1) Engineering Design Process poster • **Per team:** scissors, glue stick • **Per student:** (1) pen, (1) Engineering Notebook, (1) Engineering Design Process slider and jumbo paper clip	**DUPLICATION MASTERS** • 4.a. Design Structure Cutouts • 4.c. Design Grid Map • 4.d. Design Information • 4.e. Practice Problems • 4.g. Design Ideas - Individual Plan • 4.h. Grid Pieces • 4.i. Planning Reflection • 4.k. Evidence-Based Reasoning • 4.n. Design 1 Plan - Team • 4.o. Design Rubric • 4.q. Design Data • 4.r. Test and Evaluate **EDUCATOR RESOURCES** • 4.b. Design Structure Rank Example • 4.f. Practice Problems Answer Key • 4.j. Planning Reflection Rubric • 4.l. Evidence-Based Reasoning Rubric • 4.m. Evidence-Based Reasoning Instructions • 4.p. Teacher Observation Protocol: Try/ Test • 4.s. Test and Evaluate Rubric
• **Per class:** chart paper, Engineering Design Process poster • **Per team:** scissors, glue stick • **Per student:** (1) pen, (1) Engineering Notebook, (1) Engineering Design Process slider and jumbo paper clip	**DUPLICATION MASTERS** • 5.a. Design 2 Plan - Team • 5.b. Redesign: Evidence-Based Reasoning • 5.e. Redesign Grid Map • 5.f. Redesign Data • 5.g. Redesign Rubric **EDUCATOR RESOURCES** • 5.c. Redesign: Evidence-Based Reasoning Rubric • 5.d. Redesign: EBR Instructions • 5.h. Teacher Observation Protocol: Redesign
• **Per class:** chart paper • **Per team:** chart paper, markers • **Per student:** (1) pen, (1) Engineering Notebook, (1) Engineering Design Process slider and jumbo paper clip	**DUPLICATION MASTERS** • 6.a. Rubric for Presentation to Client • 6.b. Reflect About Engineering Design **EDUCATOR RESOURCES** • 6.c. Reflect About Engineering Design Rubric

Master Material List

	Material	Lessons Where Material is Used
Per classroom	Engineering Design Process poster*	1, 4, 5, 6
	nitrate test strips*	2
	LaMotte phosphate test tabs	2
	centrifuge tubes (15 mL)	2
	large jars (32 oz)	2
	liquid fertilizer	2
	water (tap/pond)*	2
	aquatic plant (hornwort)*	2
	3”x5” index cards (white and multi-colored)*	2
	paper towels*	2
	tape*	2
	chart paper*	1, 2, 3, 4, 5, 6
Per team (assuming 3 students per team)	plastic dropper	2
	stopwatch	2
	glue/tape	3
	chart paper*	3
	marker*	3
	glue stick	4, 5
Per student	pen	1, 2, 3, 4, 5, 6
	Engineering Notebook	1, 2, 3, 4, 5, 6
	Engineering Design Process Slider and jumbo paper clip	1, 2, 3, 4, 5, 6

*required materials not included in kit

LESSON 1

Defining the Engineering Problem

Lesson Objectives
Students will be able to:
- engage in problem scoping with the client letter.
- ask a variety of relevant questions to better understand the problem.
- identify the client.
- identify a specific and relevant end user.
- explain the criteria and constraints.
- explain the background knowledge needed to develop a solution.

Time Required
Two 50-minute class periods

Materials
Per classroom:
- Engineering Design Process (EDP) poster
- chart paper

Per student:
- 1 pen
- 1 Engineering Notebook
- 1 EDP slider with jumbo paper clip

Standards Addressed
Next Generation Science Standards: 5-ESS3-1, 3-5-ETS1-A

Key Terms
engineering design process, client, criteria, constraints

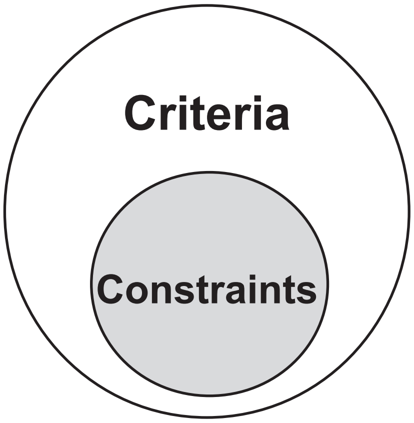
Lesson Summary
Students are introduced to the engineering challenge exploring a pond ecosystem. Students engage in problem scoping as they discuss and identify the design challenge described in a memo from the Department of Natural Resources who is requesting student engineers' help to design a solution to prevent runoff pollution that is harming the Horseshoe Pond ecosystem. Students use this information to identify the information necessary they must learn to solve the problem.

Background
Teacher Background
Teamwork: Students should be teamed strategically and may or may not be assigned roles within their team. When forming student teams, consider academic, language, and social needs. In place of strategic teaming, a random teaming can be substituted. Students will work in these teams, or "teams," of three or four throughout the unit. Effective teamwork is essential in this unit as well as in engineering in general; however, this unit does not provide specific support to develop those skills. If students do not have experience with teamwork, targeted team-building activities are highly recommended prior to beginning this unit.

Engineering Design Process: Students should have some familiarity with the engineering design process before beginning the unit. If they do not, the teacher will need to spend additional time explaining it, so this lesson may take more than one day. The engineering design process (EDP) is an iterative, systematic process used to guide the development of solutions to engineering problems. There is no single engineering design process, just like there is not one scientific method. However, the various engineering design processes have similar components. The engineering design process (EDP) is an iterative process that involves understanding the problem, learning background information necessary to solve the problem, planning, trying, testing the solution, making changes based on the tests, and communicating their ideas. Students will use a engineering design process slider throughout the unit to help them understand where they are in the design process. For more information about the steps of the engineering design process presented in this unit, see the front matter section about it.

Some common misconceptions about the EDP:
- Engineers do not have to learn anything new when they are working on a project.
  - **In reality:** Engineers need to continually learn throughout their lives.
- The engineering design process is linear, and you never need to go back to previous phases.
  - **In reality:** The EDP is a cyclical process that requires many iterations.
- Once engineers are done with a project, they never think about it again.
  - **In reality:** A project is never really "done," and engineers often continue to improve and make changes.

Criteria and constraints: One difficulty students might have is distinguishing between criteria and constraints. Criteria are the things required for a



successful design, or goals of the designed solutions. They help engineers decide whether the solution has solved the problem. Another way of thinking about criteria are that they are anything that the client and the engineers will use to judge the quality of a solution. Constraints are a specific type of criteria; they are those criteria that limit design possibilities, or the ways that the problem can be solved. If constraints are not met, the design solution is by default not a viable solution to the problem. The relationship between criteria and constraints is represented in the figure. It may be helpful to post the definitions with the figure somewhere in the classroom for future reference.

Cost is a common example of something that can be a criterion and a constraint. If the client requires engineers to stay within a specific budget, then this budget is a constraint. Any design solution that requires more money than the budget is automatically disqualified from being a quality solution. However, cost is also a relative criterion. Multiple design solutions that stay within the budget can be proposed. The costs of these solutions could be compared as one factor to determine which of the solutions is preferable.

Problem Scoping: In this lesson, students will be in the Problem Scoping section of the engineering design process, specifically on the define the problem step. Define the problem and learn about the problem combine to make Problem Scoping. In this stage, students will be first introduced to the engineering problem through a client letter and then be given a chance to ask questions to the client to receive more information about the problem. The problem statements given in the client memos purposefully do not provide all the information necessary to solve the problem. Students are tasked with generating questions about the problem to try to fill in this missing information. Based on all information from the client, students will then define the problem in terms of: what the problem is and why it is important, who are the client and end users, what are the criteria and constraints, and what other information they may need to learn about in order to solve the problem. This process of generating ideas and questions for the client is an important skill on its own both in engineering and in other fields, but it also helps to ensure that the students fully understand the problem and their task in the engineering design challenge.

Solution Generation: The Solution Generation section of the engineering design process includes plan the solution, try out the plan of the solution, test the solution, and decide whether the solution is good enough. When engineers are generating solutions, they will use iteration as a means to continually improve their solution, reflect back on the problem definition and what they have learned about the problem, and consider criteria, constraints, and trade-offs. Trade-offs involve having to make compromises about which criteria to emphasize because they compete with one another in terms

Assessments

Pre-Activity Assessment
Check students' written responses to the reflection prompts. Listen to students' verbal responses to determine their prior knowledge related to water quality and sources of pollution.

Activity Embedded Assessment
Check students' progressive understanding through their verbal and written responses during the Define the Problem activity and discussions. This is particularly important when students are answering the Define the Problem worksheet questions, since they are doing so individually and in teams; circulate during this part of the activity and check their understandings as they emerge in the written responses and team conversations. Monitor students working on the *1.e. Problem Scoping* prompts regarding the client problem, both individually and as a team.

Post-Activity Assessment
Check students' verbal responses during the whole class brainstorming session. Read student responses to the problem-scoping prompts. Use the *1.f. Questions for the Client and Problem Scoping Rubric* to provide feedback to the students.

DUPLICATION MASTERS

- 1.a. What Do You Know About Engineers?
- 1.b. Client Letter
- 1.c. Questions for the Client
- 1.e. Problem Scoping

EDUCATOR RESOURCES

- 1.d. List of Client Questions and Responses
- 1.f. Questions for the Client and Problem Scoping Rubric
- 1.g. Problem Scoping Answer Key

of making the solution effective. For example, cost could be a trade-off for durability.

Engineering notebook: Throughout the unit students will be recording information in an engineering notebook, and they will need the notebook immediately in Lesson 1. Students' engineering notebooks will support their communication of ideas and should be used consistently throughout the unit. A number of worksheets are provided as duplication masters. If these worksheets are printed for students, they should be taped or stapled into their engineering notebooks so all of the unit information is stored within the notebooks.

Vocabulary: Students will be introduced to many new science and engineering vocabulary terms throughout the unit. It may be helpful to create a vocabulary section in their notebook with term definition and memory clue or picture. Additionally, the class could maintain a word wall.

Teachers should have background knowledge and be prepared to talk about ecosystems, food webs, and how a disruption may cause harm to the organisms living in these ecosystems. Organisms are dependent on their environmental interactions. Ecosystems are dynamic in nature and their characteristics vary over time. Disruptions in an ecosystem may cause changes in its populations.

This engineering design challenge falls in the category of environmental engineering, a subset of civil engineering. Environmental engineering deals with design, construction, and maintenance or redesign of the physical and natural environment, specifically related to improving our environment. This includes, but is not limited to, the air we breathe, food we consume, water, and natural ecosystems. Additionally, students must learn concepts from ecology to assess how changes, either small or large, can impact the organisms that inhabit an ecosystem.

Before the Activity

Assemble the *Engineering Design Process* Sliders (see the front matter for how to assemble them).

Print and make copies of the following worksheets in the labeled amounts:

- *1.a. What Do You Know About Engineers* (1 per student)
- *1.b. Client Letter* (1 per student)
- *1.c. Questions for the Client* (1 per student)
- *1.e. Problem Scoping* (1 per student)

NOTE: See pages 122-124 for instructions for using notebooks for the reflection prompts rather than duplication masters.

Classroom Instruction

Introduction

1. **Introduce the unit. Say:** *We will be working on an engineering project to help keep ponds healthy by reduce the amount of pollution that gets into them.*

2. **Introduce the engineering design notebooks. Say:** *Engineers use notebooks to document their design process and keep notes. We will also be using Engineering Notebooks throughout our engineering challenge. Each day, you'll use the notebooks to take notes and record what you are learning. In addition, there are questions that you'll be asked to answer. Sometimes you'll answer the questions first on your own, then in your teams. Each day, turn in your engineering notebooks before you leave class.* NOTE: You can have your students write in their notebooks in two different colors – one for thoughts and prompts that are individual and one for thoughts and prompts that they discuss in their teams. This will help both you assess and the students recognize where ideas came from. You also may want to have students complete a Notebook Cover and start a Table of Contents page. You may choose to have students tape/glue copies of the notebook prompts and/or the duplication masters into their notebooks.

3. **Complete notebook prompts about engineering.** Have students individually answer the 2 prompts from *1.a. What Do You Know About Engineers?.* These can either be answered on copies and attached to their notebooks or written directly in their notebooks. Make sure to let them know that it is okay if they do not know very much about engineers or engineering – just have them answer these questions to the best of their ability.

4. **Discuss engineers. Say:** *We will be working as engineers to solve a problem.* **Ask:** *What do you know about engineers? Allow students to share their answers.* **Say:** *Engineers are people who solve problems by using science and mathematics. Sometime the solutions are to create a new technology or improve one that already exists, which could be objects or processes.* As a class, create a list of the different types of engineering. Explain that the problem they will be solving falls under the category of environmental engineering and draws on ecology to understand the context and to test the outcomes of the design.

5. **Introduce the Engineering Design Process.** Display the Engineering Design Process poster and pass out individual EDP Sliders and a paper clip to each student. Go through the EDP Slider and ask the students what they think each stage involves. Be sure to clarify any misconceptions and elaborate where needed. There is a detailed description of the EDP Slider in the front matter of the unit. **Ask:** *Based on what we have discussed so far, where do you think we are in the engineering design process?* **(Define).**

Activity

6. **Introduce engineering challenge through client letter.** Provide each student with a copy of the client letter. Begin by introducing students to the engineering design challenge by reading the *1.b. Client Letter*. Facilitate a discussion about the client letter, the problem, and information needed for a solution, and explain what constraints (limits to the way the problem can be solved) and criteria (solution requirements) are so

students are able to identify those pieces during problem scoping.

7. **Develop questions for the client.** First, have students individually complete *1.c. Questions for the Client.* After students have created a list of questions they have for the client, place students into teams of four. This will be their team for the unit. Have students share their list with their team and develop a team set of questions on *1.c. Questions for the Client.* Encourage students to use different color pens for their response and their team response.

8. **Share questions.** Have teams share their questions with the class. Record students' questions for the client on chart paper labeled "Questions for Client". Leave space near each question for its answer to be recorded later. NOTE: This would be an ideal place to end Day 1. If stopping at this point, **say:** *This is a great list of questions. I will email/call them to our clients so that can provide answers to some of these questions. We will see how they respond tomorrow.*

9. **Provide the client's answers to the questions.** Record the client's answers to the questions on the chart paper labeled "Questions for Client", preferably in a different color than the questions. A list of expected questions and corresponding answers are found in *1.d. List of Client Questions and Responses.* NOTE: Providing the answers from the client may be done in several ways. This includes, but is not limited to: pretending to call or email the client and ask the questions; telling the students that the client has already provided a list of answers to questions they anticipated student engineers would ask; telling them that you have had lengthy discussions about the problem, and the client has given you permission to act on their behalf; inviting a guest speaker to pretend to be the client and answer students' questions.

10. **Answer the problem scoping prompts in the notebooks.** Provide students the prompts found on *1.e. Problem Scoping*. Students answer each prompt independently in their engineering notebooks. In their teams, students then share their responses to the prompts, discuss, and develop a team response together and complete the *1.e. Problem Scoping* team prompts using a different color pen or pencil.

11. **Review the problem as a class.** After student teams have completed the problem scoping prompts, review areas that students seem to be struggling with. For example, students may need assistance clarifying who the client and end-users are and differentiating between criteria and constraints.

Closure

12. **Brainstorm what is needed to solve the problem.** Ask students to brainstorm a list of information that they think they will need to know to solve the problem. This should include the science topics they may need to learn. Record their ideas on a piece of chart paper that can be kept up for the duration of the unit.

Defining the Engineering Problem

LESSON 1

LESSON 1

Name________________________________ Date___________ Period _____

1.a. What Do You Know About Engineers?

Directions: Answer the questions as best as you can. It is okay if you do not know very much.

1. What do engineers do?

2. How do engineers solve problems?

LESSON 1

Name________________________________ Date___________ Period _____

1.a. What Do You Know About Engineers?

Directions: Answer the questions as best as you can. It is okay if you do not know very much.

1. What do engineers do?

2. How do engineers solve problems?

24 Pollutants in the Pond FT
EngrTEAMS © 2017 University of Minnesota & Purdue University Research Foundation

LESSON 1

Name________________________________ Date__________ Period _____

1.b. Client Letter

314 Horseshoe Way
City of Cottage Grove, MN 17595

Dear STEM Students,

We are contacting you today to ask for your help with a recent issue we have observed in Horseshoe Pond.

Horseshoe Pond is an important part of our community because of the large number of fish that it brings. However, Horseshoe Pond has recently been labeled as an endangered habitat. Endangered species are organisms whose numbers are so small that they could become extinct or no longer be found on Earth. When an organism is listed as endangered, the organism and its habitat are monitored and protected. Scientist and engineers with the Department of Natural Resources have been working together to monitor the pond ecosystem.

What we have learned is that the number of organisms on the endangered species list has been increasing. One of the reasons so many organisms are endangered is because the algae in the pond has been growing out of control, making it difficult for other organisms to live there. This algae problem was first noticed when farms were built near the pond. Since then, our expert scientists have been monitoring the water and have found that the amount of phosphates and nitrates in the water are much higher than normal, which is responsible for the sudden growth of the algae. The source of the phosphates and nitrates are coming from the runoff of nearby farm lands. We fear that if the amount of phosphates and nitrates continue to rise in the ponds, there will be less fish for our community.

I am contacting you for your help to design a solution to control the population of algae by reducing the amount of phosphates and nitrates that enters the pond. The City of Cottage Grove has given us a budget of $60,000 to design a solution. Additionally, it is important that the design has a positive impact on the environment. Only designs that are able to reduce runoff, is within the budget, and is environmentally friendly will be considered by the City of Cottage Grove to protect the Horseshoe Pond ecosystem. Thank you for your help.

Sincerely,

Thomas Jorgensen

Thomas Jorgensen
Department of Natural Resources

LESSON 1

Name________________________________ Date___________ Period _____

1.c. Questions for the Client

What are at least 3 questions that you want to ask the client? Ask questions that will help you understand the problem better. Make sure to ask about all important aspects of the problem.

LESSON 1

Name____________________________________ Date___________ Period _____

1.c. Questions for the Client

What are at least 3 questions that you want to ask the client? Ask questions that will help you understand the problem better. Make sure to ask about all important aspects of the problem.

1.d. List of Client Questions and Responses

1. **What is algae and how does it affect other organisms in the pond?**
   Algae are a type of organism that uses photosynthesis to produce energy. They live in fresh and saltwater. One example that everyone here probably knows about is seaweed. Algae can vary in size from a single-cell organism to a multicellular organism that can grow up to 50 meters (almost half a football field in length).

   In our pond, the algae that we observe are single-cell organisms. Usually they are not very noticeable in the pond since they are only a single cell, but recently, since there has been an increase in the phosphate and nitrate concentration, the algae population has grown to the point that it is now visible. *(At this point, you can show several images of freshwater algal blooms.)*

2. **What are phosphates and nitrates and where do they come from?**
   Phosphate and nitrates are chemical compounds that are naturally part of many environments. They are essential nutrients for plants to grow. These compounds can also be concentrated for many purposes. One example is the fertilizer that farmers use to help them grow crops more effectively.

3. **What is runoff and how do nearby farms produce the runoff?**
   Runoff is excess liquid that flows across land surfaces into nearby bodies of water. When large amounts of water are present due to rain or snowmelt, water travels towards lower elevation. While the water travels, some of it is absorbed into the land; however, as the excess water continues to travel, it can pick up various chemicals from commercial industries, or even fertilizers from farms, most notably, phosphate and nitrates.

4. **How are phosphates and nitrates connected to algae growth?**
   Like plants, phosphates and nitrates are a source of nutrients for algae; however, algae are able to grow and reproduce very fast. Under conditions with large amounts of phosphates and nitrates, algae is able to grow and multiply faster than the ecosystem can handle.

5. **How is algae growth related to the decline of other species' population?**
   Algae are able to grow very fast, which also means that they have a very short life cycle. When algae die, they undergo decay like all other organisms. This process of decay requires oxygen. When a lot of dead matter from algae accumulate, the oxygen levels in the water fall to levels that cannot support other organisms such as fish. These organisms will die due to the lack of oxygen and can cause other organisms in the ecosystem to be affected as well.

6. **What are some ways to prevent runoff?**
   Solutions to prevent runoff typically involve diverting the excess water away from sensitive ecosystems or absorbing and trapping the runoff. For example a retaining pond collects excess runoff water, whereas buffer zones have plants that absorb excess nutrients.

Name________________________________ Date___________ Period _____

1.e. Problem Scoping (1/2)

Directions: First, **on your own**, answer each of the following questions beside the “My Response” space. Then, in your teams, each person is to **share** their response and discuss. In the space, “Team Response” **write your revised answer** to the question, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. **Who is the client?**

   My response:

   Team response:

2. **What is the client’s problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.**

   My response:

   Team response:

3. **Who are the end-users?**

   My response:

   Team response:

Name________________________________ Date___________ Period _____

1.e. Problem Scoping (2/2)

4. **What will make the solution effective (criteria)? Use detailed information you have from the client.**

   My response:

   Team response:

5. **What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.**

   My response:

   Team response:

6. **Think about the problem of the runoff pollution from nearby farms. In terms of cost, how to prevent runoff, and impact on the surrounding ecosystem, what are at least 2 things you need to learn in order to design an effective solution? Make sure to consider all important aspects of the problem. Be specific.**

   My response:

   Team response:

Student Name________________________ Date__________ Period _____

1.f. Questions for the Client and Problem Scoping Rubric

Problem	Question	Learning Objectives	Rubric	
1.c	What are at least 3 questions that you want to ask the client? Ask questions that will help you understand the problem better. Make sure to ask about all important aspects of the problem.	Ask a variety of relevant questions to better understand problem.	**Asked at least 3 questions** CIRCLE: 0 1 2 3 4+	
			At least 3 questions are relevant to the problem CIRCLE: 0 1 2 3 4+	
			Considered at least 2 different aspects of the problem CIRCLE: 0 1 2 3 +	
1.e.1	Who is the client?	Identify the client.	yes no	**Correctly identified the client**
1.e.2	What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.	Explain the problem based on a synthesis of information.	yes no	**Identified problem**
		Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Explained why the problem is important**
			yes no	**Provided rationale from client information**
1.e.3	Who are the end-users?	Identify a specific and relevant end user.	yes no	**Correctly identified at least 1 end user**
1.e.4	What will make your solution effective (criteria)? Use detailed information you have from the client.	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
			yes no	**Connected information from client to criteria**

Student Name________________________________ Date___________ Period _____

1.f. Questions for the Client and Problem Scoping Rubric

Problem	Question	Learning Objectives	Rubric	
1.e.5	What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.	Explain constraints based on information.	yes no	**Identified at least 1 constraint**
			yes no	**Connected information from client to constraints**
1.e.6	Think about the problem of the runoff pollution from nearby farms. In terms of cost, how to prevent runoff, and impact on the surrounding ecosystem, what are at least 2 things you need to learn in order to design an effective solution? Make sure to consider all important aspects of the problem. Be specific.	Explain the background knowledge needed to develop a solution.	**Identified at least 2 topics they needed to learn** CIRCLE: 0 1 2 3 +	
			Topics are relevant to the problem CIRCLE: 0 1 2 3 +	
			Considered at least 2 different aspects of the problem CIRCLE: 0 1 2 3 +	

Notes:

1.g. Problem Scoping Answer Key

1. **Who is the client?**

   Thomas Jorgensen of the Department of Natural Resources

2. **What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.**

   The algae population has been growing out of control in Horseshoe Pond due to the runoff from nearby farms. They need a way to reduce the amount of phosphates and nitrates entering the lakes. The increase in algae is causing the fish and other animals in the pond to become endangered.

3. **Who are the end-users?**

   The residents of the City of Cottage Grove.

4. **What will make the solution effective (criteria)? Use detailed information you have from the client.**

   Reducing the amount of runoff (particularly phosphates and nitrates) into Horseshoe Pond and their solution needs to control algae growth and have a positive impact on the environment.

5. **What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.**

   The solution must cost less than the client's budget ($65,000).

6. **Think about the problem of the runoff pollution from nearby farms. In terms of cost, how to prevent runoff, and impact on the surrounding ecosystem, <u>what are at least 2 things you need to learn in order to design an effective solution</u>? Make sure to consider all important aspects of the problem. Be specific.**

   Answers will vary. See *1.d. List of Client Questions and Responses.*

LESSON

2 Humans and the Environment

Lesson Objectives
Students will be able to:
- describe an ecosystem.
- differentiate between abiotic and biotic factors.
- discuss the role of phosphates and nitrates in an aquatic ecosystem.
- measure nitrate and phosphate levels.
- make and record qualitative observations.
- analyze graphical data.

Time Required
Three 50 minute class periods

Materials
Per classroom:
- 1 EDP poster
- 27 nitrate test strips
- 27 large jars (32 oz)
- fertilizer
- water (from a pond or tap)
- 27 LaMotte phosphate test tabs
- 27 centrifuge tubes (15 mL)
- aquatic plant (hornwort)
- 3”x5” index cards (white and multi-colored)
- paper towels
- masking tape
- chart paper

Per team:
- plastic dropper
- stopwatch

Per student:
- 1 pen
- 1 Engineering Notebook
- 1 EDP slider & paper clip

Standards Addressed
- Next Generation Science Standards: 5-LS1-1
- Common Core State Standards - Mathematics: 5.NBT.A.1

Key Terms
ecosystems, abiotic factors, biotic factors, nitrates, phosphates, runoff

Lesson Summary
Students discuss the key components of an ecosystem. Students then work through lab stations where they examine how different amounts of fertilizer alters a pond ecosystem. Students examine the different aspects of the pond ecosystem by (1) measuring the concentration of nitrates and phosphates, (2) examining changes in plant health and algae growth, and (3) comparing the changes observed over time. Students then make connections from real-world examples and their observations to draw conclusions. The lesson concludes with students summarizing what they have learned and how this information provides insight on how they might solve the client’s problem.

Background
Teacher Background
To understand how runoff affects the environment, visit the National Aeronautics and Space Administration’s (NASA) website to briefly review the water cycle: https://pmm.nasa.gov/education/water-cycle.

Introduction to runoff: Runoff refers to excess liquid that flows across land surfaces into nearby bodies of water. When large amounts of water are present due to rain or snowmelt, water travels towards lower elevation. While the water travels, some of it is absorbed into the land; however, as the excess water continues to travel, it can pick up various chemicals from commercial industries, or even fertilizers from farms, most notably, phosphate and nitrates. These two are essential for growth of certain organisms, but high amounts can be problematic. Nutrient pollution is caused by runoff of chemicals into ecosystems. For more information and pictures of runoff and nutrient pollution, visit the Environmental Protection Agency’s (EPA) website: https://www.epa.gov/nutrientpollution/problem.

Introduction to phosphates and nitrates: Both phosphorus and nitrogen are essential for organisms in aquatic ecosystems, both directly and indirectly. Since phosphorous is the nutrient in short supply in most freshwater ecosystems, even a modest increase in phosphorus can, under the right conditions, set off a whole chain of undesirable events, including accelerated plant growth, algal blooms, low dissolved oxygen, and death of certain fish, invertebrates, and other aquatic animals. There are many sources of phosphorus, both natural and man-made. These include soil, rocks, wastewater treatment plants, runoff from fertilized cropland, and many other sources. For more information on phosphorous, refer to this video on the phosphorous cycle: https://www.youtube.com/watch?v=_IBx0zpNoEM.

Nitrate is an essential nutrient for many ecosystems. It is necessary for plant growth and maintenance; however, too much of a good thing can have harmful effects. Similar to phosphates, nitrates can also result in the overgrowth of algae or other microorganisms. Algae have a very short lifespan; in the presence of nutrient (nitrate and phosphate) rich conditions, the algae will rapidly grow and die, resulting in a high level of dead organic matter in the pond. When the organic matter decays, the process consumes oxygen in the pond, which can asphyxiate or “starve” other organisms of oxygen. This can lead to the death of organisms such as fish or tadpoles, which can heavily impact the surrounding ecosystem. For more information on the effect of nitrates on aquatic ecosystems, visit: http://www.wheatleyriver.ca/media/nitrates-and-their-effect-on-water-quality-a-quick-study/ or https://www.khanacademy.org/science/biology/ecology/biogeochemical-cycles/a/the-nitrogen-cycle.

Before the Activity

Prepare the fertilizer experiment in advance according to *2.a. Teacher Directions for Experimental Setup*.

Print and make copies of the following worksheets in the labeled amounts:

- *2.b. Video Vocabulary* (1 per student)
- *2.e. Fertilizer Experiment Packet* (1 per student)
- *2.f. Phosphate and Nitrate Direction Checklist* (1 per team)
- *2.g. Horseshoe Pond Data* (1 per student)
- *2.h. Farmer's Letter* (1 per student)
- *2.i. Horseshoe Pond Data Analysis* (1 per student)

Prepare abiotic and biotic cards and anchor chart poster. See *2.d. Abiotic vs Biotic Factors Anchor Chart.*

Classroom Instruction

Introduction

1. **Tie to the engineering problem. Ask:** *What is our engineering design problem?* Take student answers.

2. **Identify where they are in the engineering design process. (Learn) Say:** *So far, we have defined the problem with help from our client.* Point out the "Problem" block on the engineering design process and have students look at their Engineering Design Process sliders. **Say:** *Before we can start designing solutions, we need more information.* **Ask:** *What step of the engineering design process are we in?*

3. **Identify what students need to learn about. Say:** *In the previous lesson, you all brainstormed what we need to learn about.* **Ask:** *What were some of those ideas we need to learn?* Remind students to refer to their notes from the previous lesson, specifically the last question.

Activity

4. **Introduce students to the concept of an ecosystems. Say:** *We are now going to look at what an ecosystem is.* Pass out *2.b. Video Vocabulary* worksheet. Students should attempt to complete as much of the worksheet as they can while watching the video. Show the Ecosystem video to provide background information (available at: https://www.youtube.com/watch?v=aYmdrJWLQ4Y). This 2 minute video introduces the definition of an ecosystem, what it is made up of, and how humans influence ecosystems. Replay and pause the video as needed.

5. **Discuss key terms. Say:** *Based on the video, who can remind us what ____ means (ecosystems, abiotic factors, biotic factors, food web, habitat,*

Assessments

Pre-Activity Assessment
Check students' responses as they recall the client's problem and brainstorm possible areas they need to learn about to understand the problem. Check that students understand the problem.

Activity Embedded Assessment
During the anchor chart activity, check students' ability to differentiate abiotic and biotic factors. Monitor student progress as they collect measurements and record data, and discuss the results. Pay particular attention to students ability to connect how fertilizer influences plant and algae growth.

Post-Activity Assessment
As students reflect on the lesson, check students' responses to determine it they are connecting the results of the experiment to the client's problem.

DUPLICATION MASTERS

- 2.b. Video Vocabulary
- 2.e. Fertilizer Experiment Packet
- 2.f. Phosphate and Nitrate Direction Checklist
- 2.g. Horseshoe Pond Data
- 2.h. Farmer's Letter
- 2.i. Horseshoe Pond Data Analysis

EDUCATOR RESOURCES

- 2.a. Teacher Directions for Experimental Setup
- 2.c. Video Vocabulary Answer Key
- 2.d. Abiotic vs Biotic Anchor Chart
- 2.j. Horseshoe Pond Data Analysis Answer Key

ecologists). As a class, discuss each of the vocabulary terms.

6. **Create a class anchor chart of abiotic and biotic factors.** As a class, create class definitions of the terms abiotic and biotic and record them on the anchor chart. Pass out the abiotic and biotic factor cards. Each student should have one card. Ask students to place their card under either abiotic or biotic on the anchor chart poster. See *2.d. Abiotic vs Biotic Factors Anchor Chart* for example. Lead a class discussion to help students understand the meaning of these terms. Students should record this in their notebooks.

7. **Introduce nitrates and phosphates. Ask:** *What are nutrients? Are they abiotic or biotic?* Let students share their ideas. Explain to students that nutrients are things that organisms use to help them grow and stay alive. Tell them all organisms require nutrients. **Say:** *Today we will be learning more about how some nutrients affect a freshwater ecosystem like the one described by our client. We know that there are important chemicals that help plants grow. There are two nutrients that are important for freshwater plants that we will look at: phosphates and nitrates.* **Ask:** *Has anyone heard of these terms before? If so, where can we find them? What do we put on plants to make them grow better?* Fertilizer. **Ask:** *What do you think is in fertilizer that helps plants grow?* In the discussion, introduce nitrates and phosphates to the students and provide information on these two chemicals and briefly describe how they work under normal conditions.

8. **Make a connection.** Guide students towards making the connection that nitrates are important for growth of plants, not only in nature but also in industries like agriculture. Connect this back to the engineering prompt.

9. **Review the steps of the scientific process. Say:** *Sometimes engineers need to do scientific investigations to better understand their problem.* **Ask:** *What are the steps in the scientific process?* One possible answer: make an observation, form a question, form a hypothesis, make a prediction, conduct an experiment, analyze data, draw conclusions. Students should record the answers in their notebooks.

10. **Explain the setup the experiment. Say:** *Today we are going to investigate how fertilizer affects aquatic plants.* Demonstrate the experiment to the students by preparing Jar A, Jar B, and Jar C. Explain to students that this is *Day 0* of the experiment. Reserve showing them the rest of the jars until after students make their hypothesis and predictions. The teacher station should include:
    - Jar A (no fertilizer): Plant + 800 mL Water
    - Jar B (low concentration): Plant + 800 mL Water + 0.1 g crushed fertilizer
    - Jar C (high Concentration): Plant + 800 mL Water + 0.4 g crushed fertilizer

11. **Form a hypothesis and prediction.** Pass out the *2.e. Fertilizer Experiment Packet*. Have the students create and record their hypothesis and make a prediction about how fertilizer affects plants in their engineering

notebook. Encourage students to include how they think nitrates and phosphates within the fertilizer affect plant growth.

12. **Assign roles.** Each student in the team should be given a role to play during the station rotation. Here are some possible roles you might assign to the students: recorder, tester, timekeeper/timer, and materials coordinator.

13. **Setup the station rotation for data collection.** Show students the sample jars for Day 6, Day 12, and Day 18. Place each set of jars at the corresponding station around the room (a station should include Jar A, B, and C from one time point). Assign each team a set of jars. Tell students that each team will be measuring and recording the amount of nitrate and phosphate for their samples on 3”x5” index cards. Tell students they will also be recording the amount of algae in the samples using colored index cards based on a color key. For example: white = no algae or none, yellow = little algae or low, green = some algae or medium, and blue = lots of algae or high (feel free to change the color scheme based on what is available).

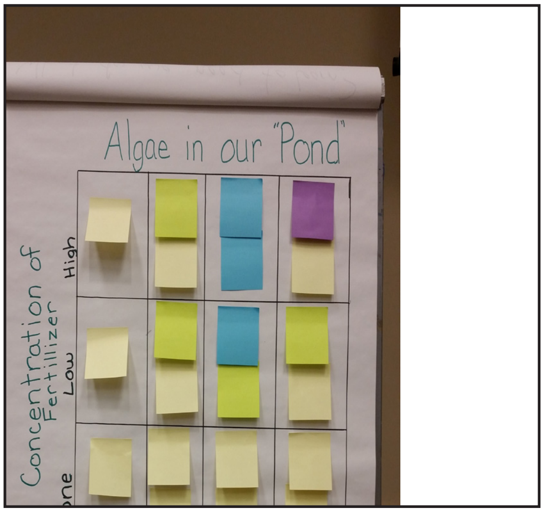
14. **Measure the amounts of nitrate and phosphate.** Using the directions on *2.f. Phosphate and Nitrate Direction Checklist*, demonstrate how to measure the phosphate testing tabs and nitrate testing strips. Have students immediately start measurements of the three samples at their station after being shown how. The student who is the recorder uses the *2.f. Phosphate and Nitrate* sheets as a checklist to ensure the team is working correctly through all the steps of the test. **SAFETY NOTE:** Have students wash their hands after handling the testing reagents and water.

15. **Determine the amount of algae.** Next, tell students what algae looks like and have them determine how much they can see in their samples. Once they have decided, the recorder should place their colored card on the class data chart. NOTE: There will be two cards per box after students have placed their cards on the chart. The example data algae chart shown below should be written on the board or on chart paper.

Algae in our “Pond”

Concentration of Fertilizer	0	7	14	21
High				
Low				
None				

Time (Days)



16. **Collect plant data and make additional observation.** Next, have the students make observations about their plant as well as any other things they see in the jars and record their data on the *2.e. Fertilizer Experiment Packet.*

17. **Collect data via a station rotation.** After students have completed their first station, have them rotate to each of the next 3 stations (three jars at each station). They will need to record observations and transfer the nitrate and phosphate measurements to their worksheet. They will not need to take nitrate and phosphate measurements at these stations. They should record how much algae they think is in the jar, but they do not need to add it to the class chart.

18. **Analyze data and draw Conclusions.** After the students have visited all of four time point stations, have them return to work on section 4 Analysis and Conclusions on the *2.e. Fertilizer Experiment Packet* in their teams. Walk around the class and listen to each team's discussion. **Ask:** *Based on your observations, how does fertilizer affect the aquatic plant? Did you notice any differences between the high and low concentrations? At what time point did you begin to notice the differences between the teams?*

19. **Review the water cycle as needed.** Students may need a brief reminder of the water cycle to answer some of the questions related to the Horseshoe pond data.

20. **Analyze graphs.** Pass out a copy of *2.g. Horseshoe Pond Data*, *2.i. Horseshoe Pond Data Analysis*, and *2.h. Farmer's Letter*. Introduce the graph of nitrate measurements of Horseshoe Pond and have students look at and begin to work on the corresponding *2.i. Horseshoe Pond Data Analysis* individually. Use this opportunity to gauge student understanding of the graph. After approximately 5 minutes, have students work on the remainder of the worksheet in their teams. Walk around and make sure their reasoning on the questions are on the right track.

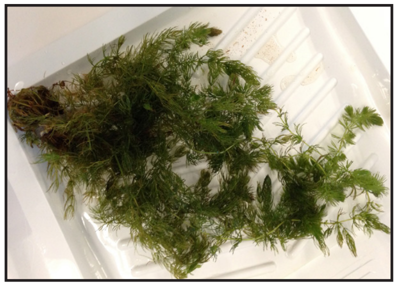
Closure

21. **Tie back to the engineering problem.** Based on what students learned today, ask them to reflect and discuss the following prompts: *How does the fertilizer get into the pond? Why is this a problem that needs to be solved? How might we go about solving this problem?*

2.a. Teacher Directions for Experimental Setup

NOTE: The samples will need to be prepared 21, 14, and 7 days in advance, in addition to today's experiment.

Materials:
- (27) 32 oz. jars with lids
- **(optional)** pond water
- hornwort (pictured right)
- fertilizer
- plastic dropper



Prior to experimental setup: Test the water (tap, pond or distilled) for the nitrate and phosphate concentration.

You may choose to either buy fresh hornwort for each day of preperation or maintain a stock of hornwort. In order to maintain a healthy stock of hornwort for use throughout the experiment:
NOTE: Pond or tap water may be used.
1. Place the hornwort in a large, transparent container filled with enough water to submerge the plant.
2. Add 0.1 grams (approximately 3 pellets) of fertilizer per liter of water. Prior to adding, crush the pellets into a rough powder.
3. Place the container in a location that receives plenty of sunlight. Loosely place a lid on top of the container so that air can circulate.
4. Harvest the hornwort as needed for each time point in the experiment. Make sure the hornwort for each jar is roughly the same size.

Setting up the experiment <u>per station</u>:
NOTE: Pond or tap water may be used.
1. Take out the three 32 oz. jars.
2. Fill each jar with approximately 800 mL of tap water.
3. Add the following amounts of fertilizer to each jar:
    - Jar A - no fertilizer
    - Jar B - 0.1 grams crushed fertilizer (approximately 3 pellets)
    - Jar C - 0.4 grams crushed fertilizer (approximately 12 pellets)

   NOTE: Other brands of fertilizer may be used, but will require testing. In the high concentration of fertilizer, the nitrate concentration should measure roughly 40-50 ppm and phosphate should measure above 4 ppm after application of the fertilizer. In the low concentration, nitrate and phosphate concentration should be about 10-20 ppm and 3-4 ppm, respectively. If using solid, time-release pellets, crush the fertilizer into a powder prior to application for best results.
4. Harvest/trim the hornwort from the stock and add hornwort to each jar (hornwort will require trimming to ensure similar sizes for each condition). The hornwort should take up around 40-50% of the space in the jar.
5. Loosely place lid on top of the jar so that air can be circulated. Place a piece of tape on each jar and label the day and condition.

2.a. Teacher Directions for Experimental Setup

6. Set up a grow light and place the jars within proximity of the light (approximately 12”-18” away - pictured right). Using a mechanical outlet timer, set the grow light ON for 16 hours of the day. **CAUTION:** Grow lights produce light that is harmful to the naked eye. Set up the grow light in an area where there is little to no traffic or place a barrier around the grow light if needed. NOTE: For Day 0, you will be preparing 3 sets of jars (2 for each station and 1 for teacher demonstration). A preparation checklist is shown below.

Day	21	14	7	0
Stations	1 & 5	2 & 6	3 & 7	4, 8, & demo samples

Day 0 station: Jar A, Jar B, Jar C

Day 7 station: Jar A, Jar B, Jar C. The plant with no fertilizer is discolored, while the plants with fertilizer are green. The plant in the high concentration has grown.

Day 14 station: Jar A, Jar B, Jar C. The plant in the no fertilizer condition is discolored and lost its structure, while the plants with fertilizer are green. There is presence of algae, small amounts in the low concentration fertilizer condition and highly visible amounts in the high concentration condition.

Day 21 station: Jar A, Jar B, Jar C. Again the plant without fertilizer is discolored, while the jars with fertilizers have healthy plants. Also, the jar with a high concentration of fertilizer has a dense amount of algae.

LESSON 2

Name______________________________ Date__________ Period _____

2.b. Video Vocabulary

Directions: Write the definition for each word in the space provided.

Ecosystem	______________________________ ______________________________ ______________________________
Biotic Factors	______________________________ ______________________________ ______________________________
Abiotic Factors	______________________________ ______________________________ ______________________________
Food web	______________________________ ______________________________ ______________________________
Habitat	______________________________ ______________________________ ______________________________
Ecologist	______________________________ ______________________________ ______________________________

2.c. Video Vocabulary Answer Key

NOTE: Definitions may vary

Term	Definition
Ecosystem	community of living things interacting with the nonliving things in the environment
Biotic Factors	all the living things in the environment
Abiotic Factors	all the non-living things in the environment
Food web	describes how energy moves through an ecosystem
Habitat	a place where an organism lives
Ecologist	scientist who studies ecosystems

2.d. Abiotic vs. Biotic Factors Anchor Chart

Directions: Create cards by writing one word on a 3" x 5" card. Create enough cards so that each student has a card. Here are some possible words that may be used.

- Water
- Trees
- Fish
- Oxygen
- Mushrooms
- Phosphates
- Birds
- Insects
- Grass
- Sand
- Nitrates
- Algae
- Snails
- Cows
- Air
- Whale
- Water lily
- Frog
- Rock
- Raccoon
- Salt

Create the anchor chart on a poster paper. NOTE: The blue text is your key for reference.

Abiotic Factors	Biotic Factors
Definition: All non-living things in an environment	**Definition:** All living things in an environment
Examples • water • oxygen • phosphates • sand • nitrates • air • rock • salt	**Examples** • trees • fish • mushrooms • birds • insects • grass • algae • snails • cows • whale • water lily • frog • raccoon

LESSON 2

Name______________________________ Date___________ Period _____

2.e. Fertilizer Experiment Packet (1/6)

Part A. Making Hypotheses and Predictions

Directions: Look at the samples that the teacher has provided. Create a hypothesis and prediction about how fertilizer affects plants in the space provided.

Hypothesis:

____

____

____

Prediction:

____

____

____

Part B. Data Collection

Directions: As you move from each station, record the station number in the space provided in the table. Next, record your measurements and observation in the tables below.

Station #_____ Day 0	**Observations**		
	Jar A (no fertilizer)	Jar B (low concentration)	Jar C (high concentration)
phosphate level			
nitrate level			
amount of algae (none, low, medium, high)			
description of plant			
descriptive observations			

Name____________________________________ Date_____________ Period ______

2.e. Fertilizer Experiment Packet (2/6)

Station #_____ Day 6	**Observations**		
	Jar A (no fertilizer)	Jar B (low concentration)	Jar C (high concentration)
phosphate level			
nitrate level			
amount of algae (none, low, medium, high)			
description of plant			
descriptive observations			

Station #_____ Day 12	**Observations**		
	Jar A (no fertilizer)	Jar B (low concentration)	Jar C (high concentration)
phosphate level			
nitrate level			
amount of algae (none, low, medium, high)			
description of plant			
descriptive observations			

Name________________________________ Date__________ Period _____

2.e. Fertilizer Experiment Packet (3/6)

Station #_____ Day 18	**Observations**		
	Jar A (no fertilizer)	Jar B (low concentration)	Jar C (high concentration)
phosphate level			
nitrate level			
amount of algae (none, low, medium, high)			
description of plant			
descriptive observations			

Part C. Analyze the Data

Directions: Please answer the following questions in the spaces provided.

1. For our experiment, list 2 abiotic factors and 2 biotic factors.

Abiotic Factors ______________________________

____

Biotic Factors ______________________________

____

2. Explain why the factors you listed above are abiotic or biotic.

Name__________________________________ Date____________ Period _____

2.e. Fertilizer Experiment Packet (4/6)

Understanding the "Algae in our Pond" chart

3. What does it mean if you move up in the charts?

4. What does it mean to move right on a chart?

5. Where on the chart would you find a jar that is:

    - old and has no fertilizer?
    - young and has high fertilizer?
    - six days old and has low fertilizer?

Analyze the data

Directions: Use observations and the heat chart to answer the following questions

6. Did you notice any differences between the high and low concentrations of fertilizer samples? Please describe.

7. Did you notice any changes in the jars over time? Please describe.

Name________________________________ Date___________ Period _____

2.e. Fertilizer Experiment Packet (5/6)

8. Did algae appear in any of the jars? Circle one: Yes No

- If so which ones? (List them.)

- What patterns do you see in the list of jars that you just provided?

- Now look at the chart. Where on the chart is there the most algae?

- Where on the chart is there the least amount of algae?

- If we let the jars sit for six more days, what would you expect to see in the jars? Please explain.

Name________________________________ Date___________ Period _____

2.e. Fertilizer Experiment Packet (6/6)

9. What would you expect to see if we measured a sample that had a medium level of fertilizer each day?

10. How does fertilizer affect <u>algae</u> growth over time? Please explain and justify why you believe this.

11. How does fertilizer affect <u>plant health</u> over time? Please explain and justify why you believe this.

LESSON 2

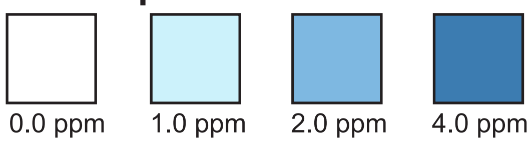
Name________________________________ Date____________ Period _____

2.f. Phosphate and Nitrate Direction Checklist

Phosphate Test:

Directions	Completed		
	A	B	C
Use the dropper to fill the centrifuge tube (15 mL) with 10 mL of water from the jar.			
Open and release the LaMotte phosphate test tabs into the centrifuge tube.			
Gently shake the centrifuge tube until the test tab dissolves.			
After the test tab dissolves, wait 5 minutes.			
Compare the color of the water with the color chart.			

Phosphate Concentration

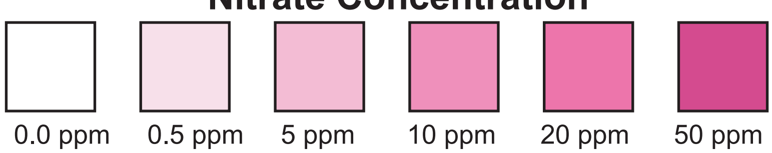


NOTE: Total phosphate in the high concentration condition should be more than 4 ppm (very dark blue) and 2-4 ppm (dark blue) in the low concentration condition.

Nitrate Test:

Directions	Completed		
	A	B	C
Submerge testing strips below the surface of the water for 2 seconds.			
Place on a paper towel and allow the testing strip reaction to run to completion for 1 minute.			
Compare testing strip to the color chart on the bottle.			
Repeat for each condition.			

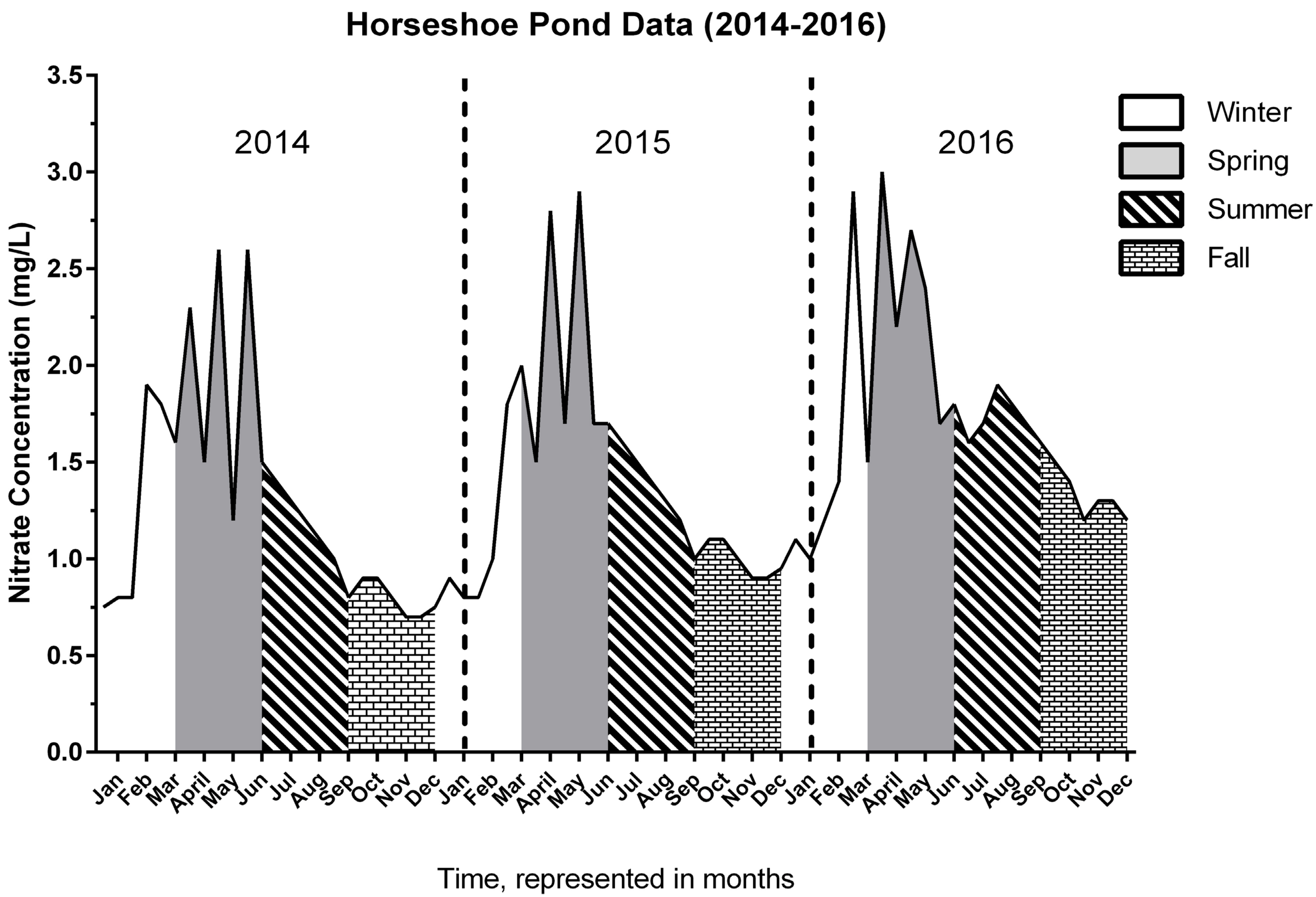
Nitrate Concentration



NOTE: Total nitrate levels in the high concentration condition should be between 20-50 ppm (very dark pink) and 3-10 ppm in the low concentration condition (light pink).

Name________________________ Date__________ Period _____

2.g. Horseshoe Pond Data



Name________________________________ Date___________ Period _____

2.h. Farmer's Letter

314 Costa Rd
Horseshoe City, MN 17596

Dear Student Engineers,

I was requested by your local Department of Natural Resource to give a brief introduction to the process of fertilization.

Here at Costa Farms, we grow a variety of different crops. In order to meet our production goals, we need to make sure that all the plants have the proper amount of nutrients. Some of these nutrients include nitrates and phosphates. Without these, our crops would grow very poorly.

The best time to apply fertilizer is just before planting our crops, right before spring comes. However, depending on several factors, including the price of fertilizer, availability of tools, and the cost of labor, we can choose to apply fertilizer in the fall just before the snow starts falling. If the conditions are just right, we do what is called a split application, where we put half of the fertilizer in the fall, and the other half in the spring. This helps with the costs, while still providing the necessary amounts of nutrients for our crops.

One small problem we have to consider with applying fertilizer in the fall is that nitrogen is a very mobile nutrient, meaning that it can be washed away due to snowmelt that happens during the months of February or March. We have to be careful about how much fertilizer we introduce into the soil at any given time.

Warm regards,

Carla Costa

Carla Costa
Costa Farms, MN

Name________________________________ Date____________ Period _____

2.i. Horseshoe Pond Data Analysis (1/2)

Directions: Read the farmer's letter and examine the Horseshoe Pond Data. Answer the questions below.

1. What is being shown on the x-axis?

2. What is being shown on the y-axis?

3. What do the patterns on the graph represent?

4. In your own words, describe what patterns or trends you see in the data points on the graph.

5. Based on the farmer's letter and the graph:

   - What do you see happening to the nitrate concentration during the months of February/March?

   - From your own experience, what is the weather like during February and March?

Name________________________________ Date__________ Period _____

2.i. Horseshoe Pond Data Analysis (2/2)

- Where is the nitrate coming from?

- How do you think the nitrates are getting to the pond? Please explain.

6. What events do you think are happening during March - June that is causing the sharp increase in nitrate levels? (List two)

7. Write down the nitrate concentration at December for each year in the table. What trend or pattern do you notice?

Data	**Nitrate Concentration (mg/L)**
Dec. 2014	
Dec. 2015	
Dec. 2016	

8. Based on the data, what conclusions can you make about the concentration of nitrogen over the three years in the pond?

2.j. Horseshoe Pond Data Analysis Answer Key

1. What is being shown on the x-axis?
   Time (in monthly increments)

2. What is being shown on the y-axis?
   Nitrate concentration in Horseshoe Pond

3. What do the patterns on the graph represent?
   The seasons: Summer, Fall, Winter, Spring

4. In your own words, describe what is being shown in the graph.
   The graph is showing the change in nitrate concentration over the span of three years. We see a large increase in nitrate concentration during March - June months.

5. Based on the farmer's letter and the graph:
   - What do you see happening to the nitrate concentration during the months of February/March?
     The increase in nitrate concentration.
   - From your own experience, what is the weather like during February and March?
     Answers will vary (snowing, raining, cold in February but getting warmer in March)
   - Where is the nitrate coming from?
     The nitrate is coming from the farms that fertilized their crops in the fall. Snow washed away the fertilizer from the farm and carried it to the pond.
   - How is it getting to the pond? Please explain.
     Runoff: At the end of winter, the temperature rises and snow begins to melt, which carries the fertilizer from the farms to the ponds.

2.j. Horseshoe Pond Data Analysis Answer Key

6. What events do you think are happening during March - June that is causing the sharp increase in nitrate levels? (List two.)
   Fertilization of the crops and rain are causing nitrates to runoff and get to the pond.

7. Write down the nitrate concentration at December for each year. What trend or pattern do you notice? **(Values are approximate.)**
   The concentration of nitrate is increasing every year.

Data	Nitrate Concentration (mg/L)
Dec. 2014	**0.75**
Dec. 2015	**0.95**
Dec. 2016	**1.20**

8. Based on the data, what conclusions can you make about the concentration of nitrogen over the three years in the pond?
   The runoff carrying the fertilizer from the farms is causing the nitrate concentration to spike during March - June and causing a steady increase of nitrate over time.

LESSON 3

Food Webs

Lesson Objectives
Students will be able to:
- define vocabulary relevant to pond and pond ecosystems.
- create a food web for a pond ecosystem.
- describe how changes at one level of an ecosystem affect other related organisms.

Time Required
Two 50 minute periods

Materials
Per classroom:
- 1 EDP poster
- tape

Per team:
- glue or tape
- chart paper
- marker

Per student:
- 1 pen
- 1 Engineering Notebook
- 1 EDP slider & paper clip

Standards Addressed
Next Generation Science Standards: 5-LS2-1, 5-PS3-1

Key Terms
producer, consumer, decomposer, herbivore, omnivore, carnivore, food chain, food web

Lesson Summary
In this lesson, students explore the interdependence of organisms within a community by constructing a pond food web. Using the models generated, students discuss the movement of energy through an ecosystem and participate in a gallery walk to share their models. Students use this information to make prediction about how biotic and abiotic changes in the ecosystem alter the food web. Students connect how fertilizer runoff affects the ecosystem described in the client letter.

Background
Teacher Background
Ecosystems maintain homeostasis by balancing the needs of consumers with producers. Sudden or drastic changes in any populations will cause an imbalance in the food chain and result in the decline of another species in the ecosystem. The decrease in wildlife presented in the client letter is due to runoff from nearby farmlands. These farmlands utilize fertilizers that contain nitrates, an important compound that is necessary for the growth of plants and algae. These phosphates and nitrates are being introduced into the pond/ pond ecosystem are also responsible for the out of control growth of algae and subsequent build up of organic matter. The accumulation of dead algae depletes the oxygen in the water during the process of decay, which causes other aquatic organisms reliant on the dissolved oxygen to die. This lesson is designed to teach students how imbalances in the food web impacts all other organisms.

Before the Activity
Prepare a set of *3.a. Pond Organism Cards* and place them in an envelope for each student team.

Print and make copies of the following worksheets in the labeled amounts:
- *3.b. Organism Information Sheet* (1 per team)

Create a teacher example of food web using the same cards as the students. Refer to *3.c. Example Food Web* if needed.

Load the video of a pond (available at: https://youtu.be/H8EMn_21T4o) and the website on food chains (available at: http://www.sheppardsoftware.com/content/animals/kidscorner/games/foodchaingame.htm).

Classroom Instruction
Introduction
1. **Introduce a pond ecosystem. Ask:** *What are your experiences visiting nearby ponds?* Encourage students to share their experiences and observations.

2. **Exploring a pond.** Show students a video of a nearby pond such as this one: https://youtu.be/H8EMn_21T4o (7 minutes). Ask students to name organisms they think are present in a pond ecosystem based on the video as well as their experiences. Review and ask students if they know what an herbivore, omnivore, or carnivore are. Have the students write down

the class-generated definition of each of these vocabulary words in their engineering notebooks. **(Optional)** Take a field trip to a local pond.

3. **Tie to the engineering problem. Say/Ask:** *What is the problem our client needs help solving and why is it a problem?* Allow students to answer. Show students images of ponds, both health and unhealthy. Have students make observations about the ponds. Ask students to share the similarities and differences in the ponds. Encourage students to share their ideas about what causes these differences. **Say:** *Today we are going to learn how changing one thing in an ecosystem can impact other things in things in that environment.*

4. **Identify where they are in the engineering design process. (Learn)** Refer students to their EDP Sliders. **Ask:** *What step of the engineering design process are we in?*

Activity

5. **Introduce vocabulary. Ask:** *What do all the herbivores, omnivores, and carnivores have in common with each other?* They all eat other organisms. *Why do they need to eat?* To get energy to survive. Tell students that when organisms eat another organism, we call it a consumer. **Ask:** *What do herbivores eat?* Herbivores eat plants. *Do plants need energy to survive?* Yes, plants need energy to survive. *Where do they get their energy from?* Plants get their energy from the sun. Share with students that plants can "produce or make" their own food so we call them producers. **Ask:** *Does anyone know what a fungus eats?* Explain the term decomposers to the students. Have students record the definitions in their notebook.

6. **Create food chains.** As a class create and discuss simple food chains using the following website: http://www.sheppardsoftware.com/content/animals/kidscorner/games/foodchaingame.htm. This site walks through 7 different food chains. As the students create the food chain, have them record them in their engineering notebook. Emphasize that the arrows show how the energy moves through the food chain from one organism to another. Also point out organisms that may not be familiar to them such as plankton and algae. Ask students to point out the producers, consumers, and decomposers in the food chain. (**Optional)** Students may do this individually or in small teams if they have access to computers.

7. **Compare food chains.** Once all 7 food chains are completed, ask students to compare them to find similarities between them. Possible answers may include: they all have three or more organisms, they all begin with a producer and the consumers then eat the producer, each food chain has two or more consumers, and some food chains have organisms that are found in more than one food chain. Explain to students that sometime organisms can be in many food chains.

8. **Create food webs. Say:** *Today we are going to work in our teams to create a model of the some of the food chains that are found in a pond*

Assessments

Pre-Activity Assessment
Ask students to name organisms they think are present in a pond ecosystem. Check students' understanding of consumption classifications (omnivores, carnivores, and herbivores).

Activity Embedded Assessment
Monitor students' progress during the food web poster. During the gallery walk, check that students are able to classify each organism as either a producer, consumer, or decomposer and that they understand that the arrows in the food web shows the direction that energy flows through the system.

Post-Activity Assessment
As students discuss the reflection prompts, check students responses to determine it they are able to predict how changes in one part of the ecosystem affect the other parts of the ecosystem. Also check that students are able to recognize how these changes relate to the engineering problem.

DUPLICATION MASTERS

- 3.a. Pond Organism Cards
- 3.b. Organism Information Sheet
- **(Optional)** 3.d. Bonus Pond Organisms

EDUCATOR RESOURCES

- 3.c. Example Food Web
- **(Optional)** 3.e. Bonus Example Food Web

ecosystem and show how they are connected to each other. Distribute the envelopes containing the *3.a. Pond Organism Cards* and the *3.b. Organism Information Sheet* to each team. Explain that they should create a model that shows how energy moves through the ecosystem based on the information on the sheets provided. Let them know that it is okay if an organism is found in more than one food chain. Have students organize the cards to create a food web. After the students have organized their cards, have them tape or glue it to a piece of chart paper. Next, have the students label (letter and color) each organism (For example: P for producer - green, C for consumer - red, and D for decomposers- orange.) Finally, students should draw arrows between organisms to show how energy moves through the food web. Refer to *3.c. Example Food Web* to view a completed food web. NOTE: Students may have trouble drawing the arrows in the correct direction. Ensure that the students understand that the arrows represent the direction energy flows through an ecosystem. During this time, listen to students conversations and ask them probing questions about the food web they are creating. **(Optional)** You may have students use the *3.d. Bonus Pond Organisms* and the to create a more complex food web. Refer to the *3.e. Bonus Example Food Web* to view a completed food web.

9. **Have a food web gallery walk.** When each team is finished, post each team's chart paper in a location all the students can view. Have students walk around and view the various posted charts. As they examine other charts, have them record in their notebooks the similarities and differences between the different food web as well as one food chain from each of the food web.

10. **Discuss food webs and energy flow.** Lead a class discussion on the students' findings. Focus the conversation on how energy moves through the food web and the relationships between organisms. Reveal your chart and **ask:** *What differences do you observe between your chart and this one? What would happen if the algae population grows very large?* Students will most likely say that organisms that eat (get their energy from) algae will also increase in population because they have more food. However, this is not the case. Explain to students that when algae die, they also trap oxygen. **Ask:** *What happens to organisms when they don't have oxygen?* They die. *So what would happen to the food web if algae populations get very large?* All the organisms in the pond that need oxygen would die.

11. **Make predictions.** Present students with questions that allow them to make a prediction about what would happen to the food web if something happened to one or more of the organisms in the ecosystem. Possible questions include: *What would happen if the ____________ population started to die? What would happen if the plants in the pond/pond died? What factors could cause a decrease in any of the populations shown on the food web? What would happen if humans used bug killer to remove the mosquitoes in the ecosystem?*

12. **Tie back to the engineering challenge.** Now begin to relate the client letter to the food web. **Ask:** *Can someone remind me what issue our client is facing? How does it relate to the food web we have here?* Try and move the discussion towards runoff from the nearby farms being the source of nitrates and other chemicals responsible for causing the algal blooms and how the algal blooms affect other organisms in the food web.

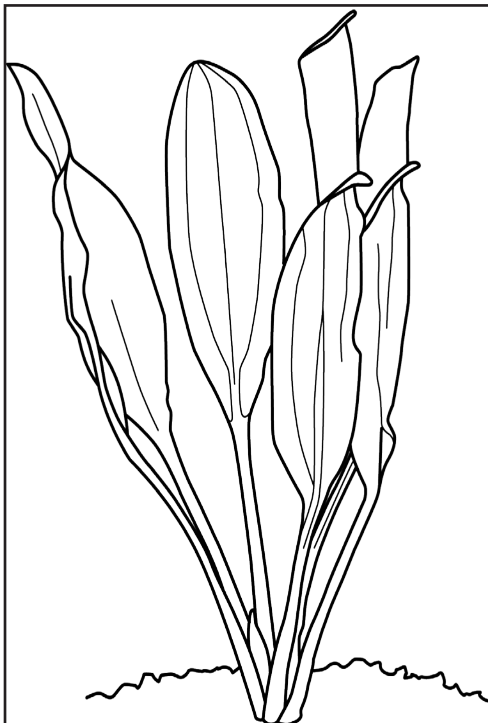
Closure

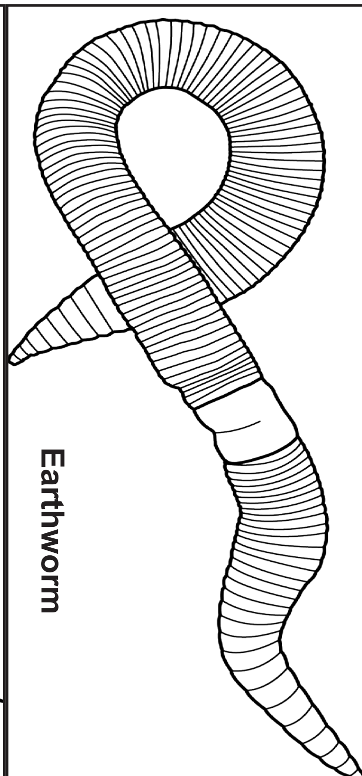
13. **Tie to the engineering problem.** Have the students discuss the following prompt: *What do you think would happen if we introduce too much phosphate or nitrates into a pond ecosystem? How would this affect other living organisms living nearby the pond?* Encourage students to refer to the food webs they made (be sure to cover algae in the discussion).

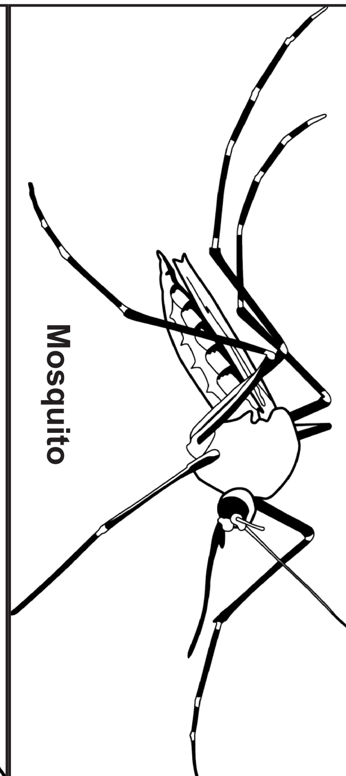
14. **Share new information.** In their teams, have students share something new they just learned, a reminder about something they already knew, and a question that they have about food webs. Have the students write these down in their engineering notebooks.

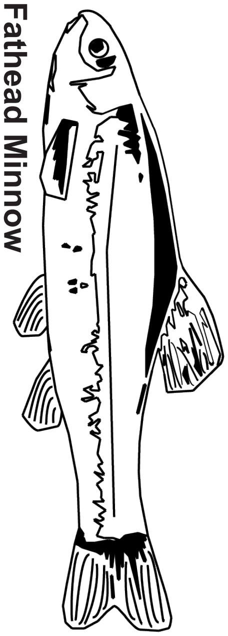
LESSON 3

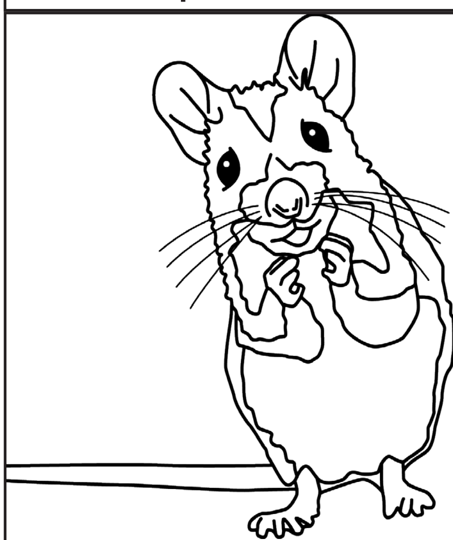
3.a. Pond Organism Cards (1/2)

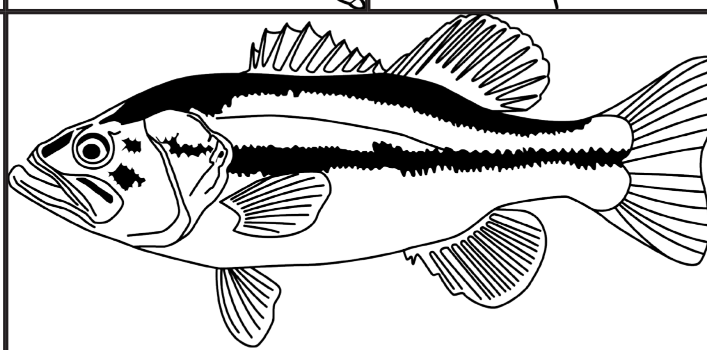

Aquatic Plant

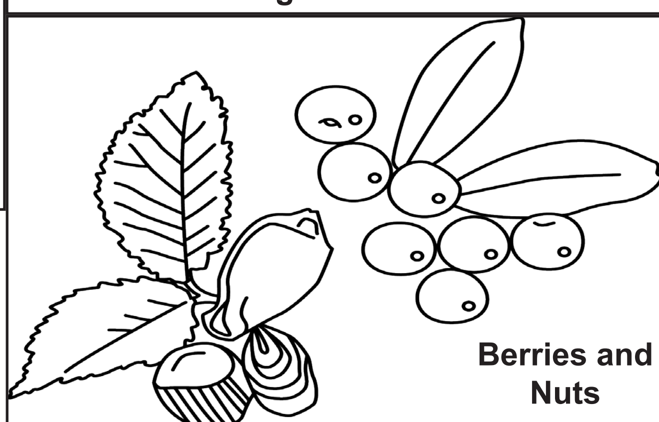

Earthworm


Mosquito


Fathead Minnow

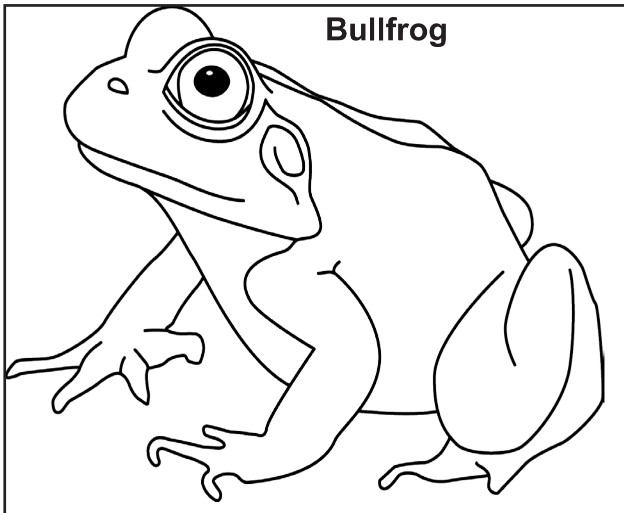

Field Mouse

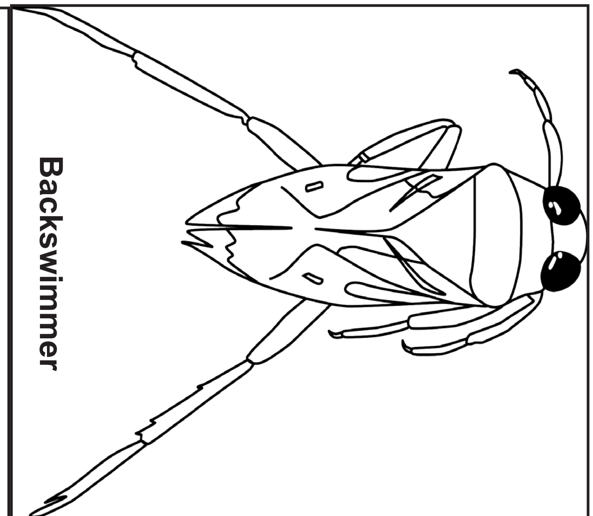

Largemouth Bass

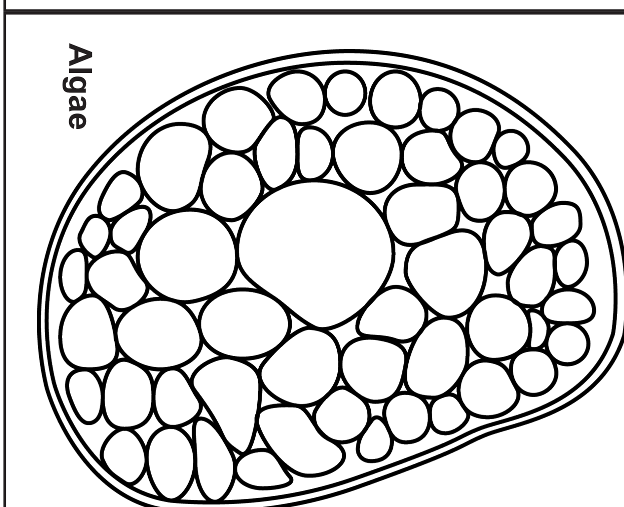

Berries and Nuts

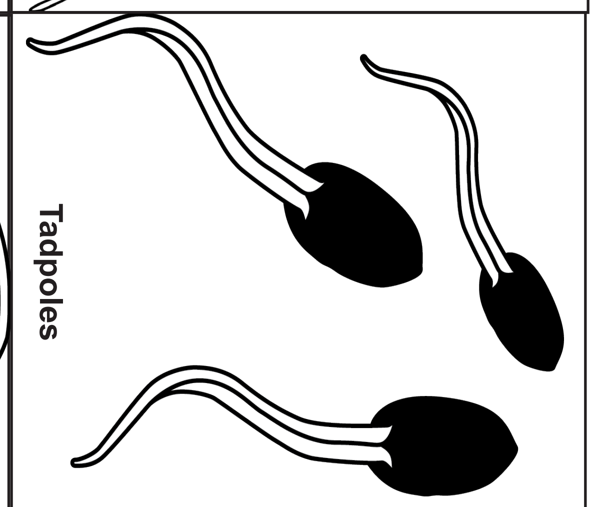
LESSON 3

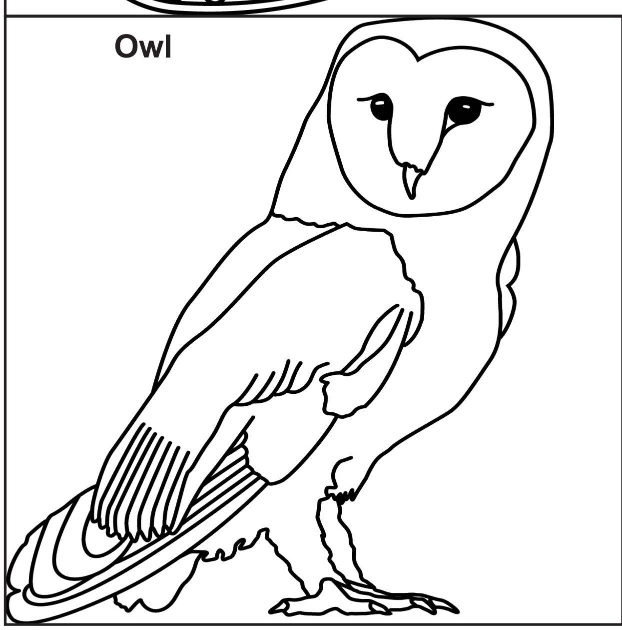
3.a. Pond Organism Cards (2/2)

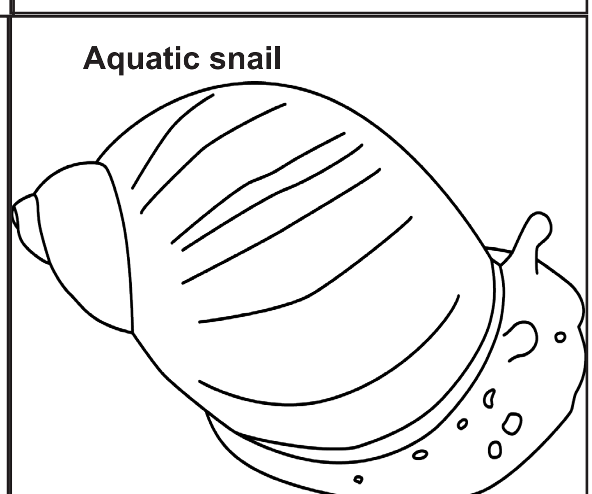












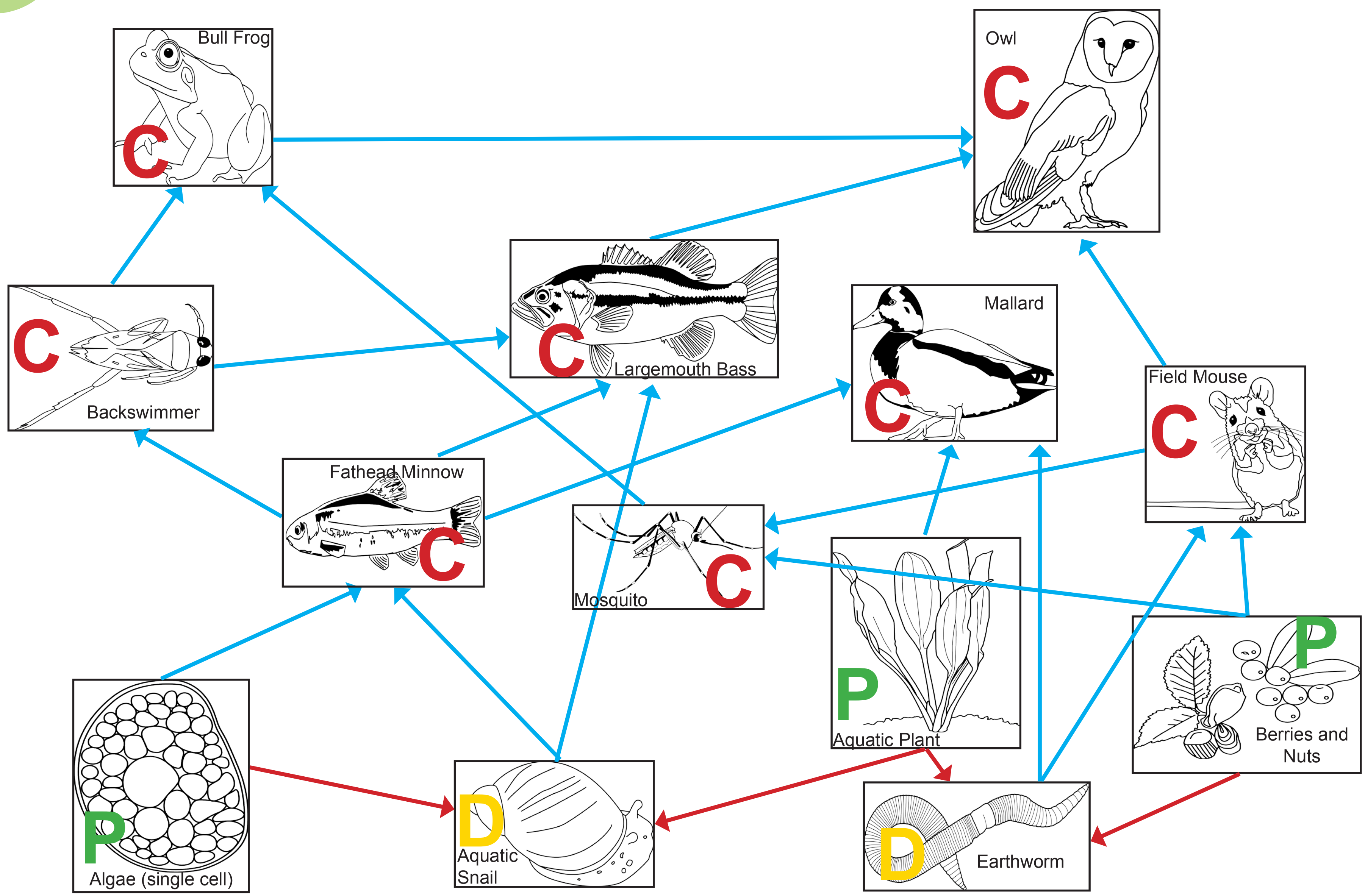
LESSON 3

Name__________________________________ Date____________ Period _____

3.b. Organism Information Sheet

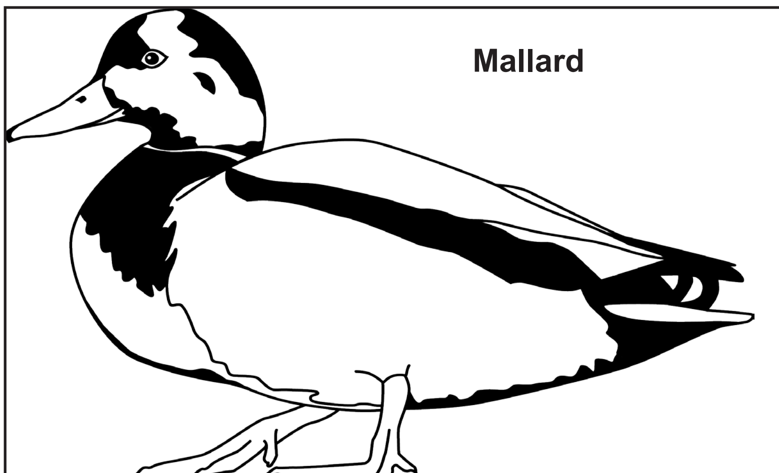
Organism	Description
Algae	Photosynthetic, single-celled organisms. These normally cannot be seen without a microscope, unless the population rapidly increases.
Aquatic Plants	Various forms of aquatic plants including water lettuce, hyacinth, hornwort, and many others. Requires sunlight to grow.
Aquatic Snail	Snail that lives in the water. Diet consists of algae or decaying plants.
Backswimmer	Aquatic insect that usually swims on its back. They have unique breathing system that allows them to use the oxygen in the water. Diet consists of other small insects, tadpoles, or small fish.
Berries and Nuts	Plants and fruits that are located in the surrounding area.
Bullfrog	Amphibious frog that has an olive green back with brownish markings. Its diet consists of worms, insects, snails, and tadpoles.
Earthworm	Earthworms get their nutrients from things in the soil, such as decaying roots and leaves.
Fathead Minnow	Small freshwater fish whose diet consists of algae, zooplankton, and aquatic snails.
Field Mouse	Small mammal whose diet consists of seeds and worms.
Largemouth Bass	Olive-green freshwater fish that grows to be about two feet long. Diet consists of insects, small fish, and snails.
Mallard	A wild duck that grows to be 20-26 inches long. Males have colorful feathers while females are brown. Diet consists of insects, aquatic plants, and small fish.
Mosquito	Small insect that drinks the blood of mammals. They also consume plant nectar (flowering berries).
Owl	Large, nocturnal bird. Diet consists of small animals including amphibians, fish, and mammals.
Tadpoles	Early stage in the life cycle of a frog whose diet consists of mostly of algae.

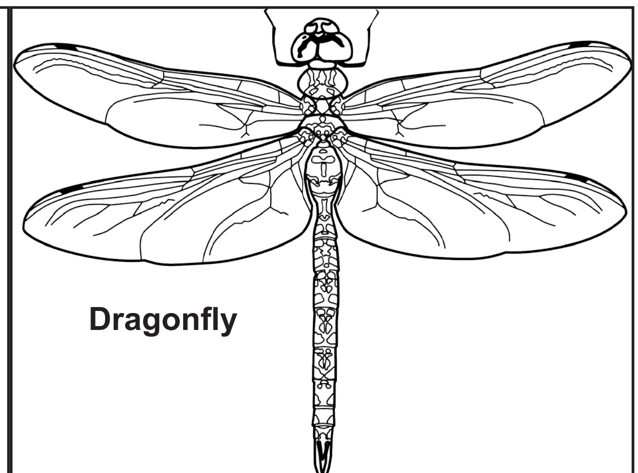
3.c. Example Food Web

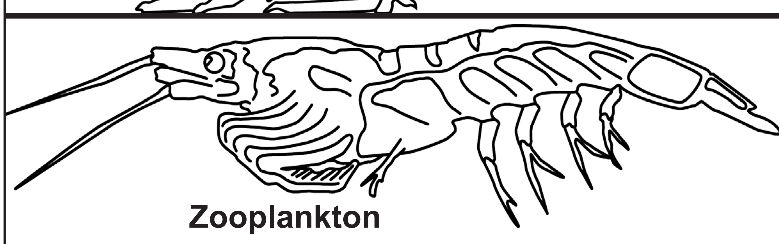


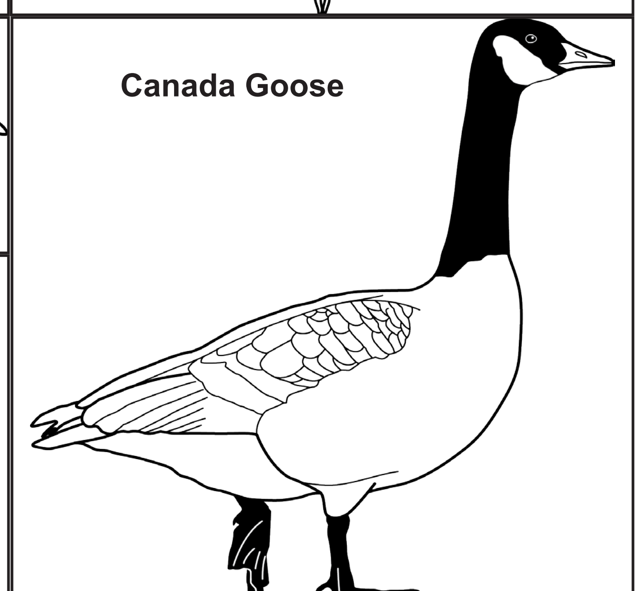
3.d. Bonus Pond Organisms

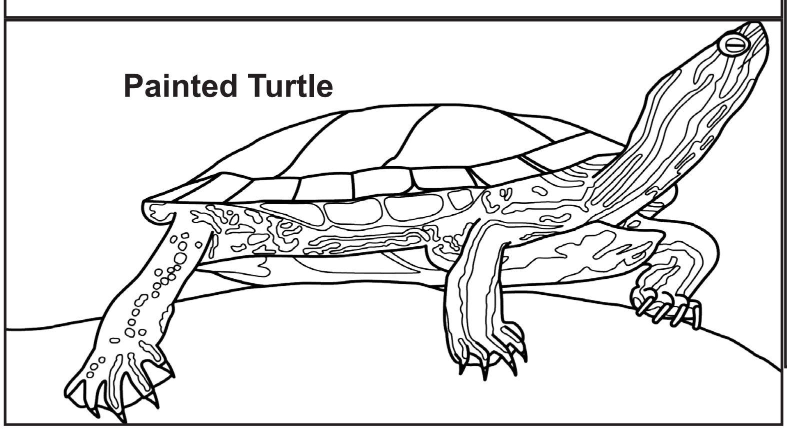
Organism	Description
Canada Goose	A large aquatic bird that eats primarily plants, but have been known to also eat small insects and fish.
Dragonfly	Insect that lives near bodies of water and eats other small flying insects.
Painted Turtle	Slow moving turtle that has a dark and smooth shell with red, orange, or yellow stripes. Diet consists of small fish, worms, insects, and aquatic plants.
Tadpoles	Early stage in the life cycle of a frog whose diet consists of mostly of algae.
Zooplankton	Microscopic organism whose diet consists of algae and other microorganisms.





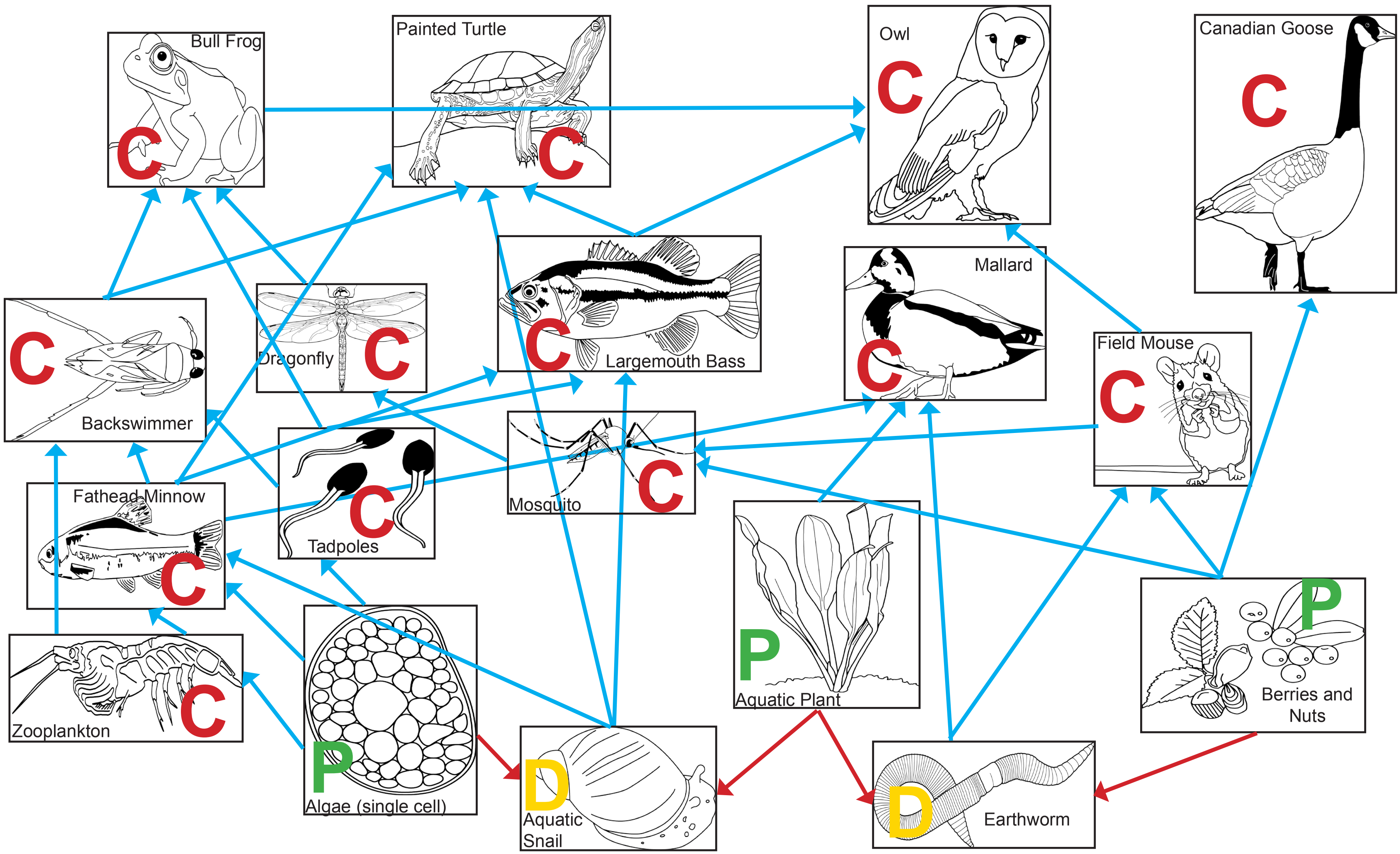






Name______________________ Date__________ Period _____

3.e. Bonus Example Food Web



LESSON

A Optional Guest Speaker

Lesson Objectives

Students will be able to:

- interact with a guest speaker who is involved with ecosystem balance.
- discuss findings based on the guest speaker's experience.

Time Required

One 50-minute period

Materials

Per student:

- 1 pen
- 1 Engineering Notebook

Standards Addressed

Next Generation Science Standards: 5-ESS3-1

Lesson Summary

Students interact with a guest speaker that is involved with ecosystem balance on a regular occurrence. Students learn about the duties and responsibilities of the guest speaker and discuss how this new information fits into the context of the client problem.

Background

Before the Activity

Contact a member of the community to speak to the class about their job and how runoff and pollution issues occurring locally affects their work. Some possible guest speakers include, but are not limited to: persons working for the Department of Natural Resources, state or national parks, or local university (possibly researchers in ecology or agriculture). Inform the potential guest speaker that he/she will give an informal presentation (approximately 20-30 minutes) about his or her job and their involvement with natural or artificial ecosystems. Give a brief description of what the students are learning and the design project so the presenter can prepare their talk accordingly.

Classroom Instruction

Introduction

1. **Introduce the guest speaker.** Introduce the guest speaker and make a connection between the guest speaker's job and the subject of today's talk. Also, be sure to tie in the design challenge into the conversation.

Activity

2. **Listen to the guest speaker.** Have students listen to the guest speaker. Encourage students to ask questions about his/her job.

3. **Reflect on the presentation.** After the guest speaker is done, have students individually answer the following prompts in their notebooks:
    - What did you learn about the speakers job?
    - What other information did you learn?
    - How was what you learned today related to our engineering problem?

4. **Share with teams.** Have students discuss their answers to the prompts with their teams.

5. **Discuss with the class.** After students are done discussing, have the teams share the new information they have learned with the class. Write these up on the board and have students incorporate the new information into their notebooks.

Closure

6. **Complete an exit ticket.** Have students record one way they think they will use this information to help solve the problem. This may be done on a sheet of paper or a sticky note. Collect the students responses.

Optional Guest Speaker

Assessments

Pre-Activity Assessment
Monitor students' responses as they relate the guest speaker's job to the design challenge.

Activity Embedded Assessment
Check students' responses to the reflection prompts and monitor students' discussion with their teams. Check to see if students are connecting the new information to what they already know.

Post-Activity Assessment
Check students' responses to the exit ticket. Check to see if students make a connection between the new information that they learned and the client's problem.

LESSON 4 Designing a Solution

Lesson Objectives

Students will be able to:

- brainstorm methods and plan a strategy to prevent runoff pollution.
- communicate design idea through drawing, including labels for materials and function of parts.
- select potential solution through systematic evaluation of various solution based on the problem.
- construct, test, and evaluate their design.

Time Required

Three 50-minute class periods

Materials

Per classroom:

- 1 EDP poster

Per team:

- scissors
- glue stick

Per student:

- 1 pen
- 1 Engineering Notebook
- 1 EDP slider & paper clip

Standards Addressed

- Next Generation Science Standards: 3-5-ETS1-A, 3-5-ETS1-B
- Common Core State Standards - Mathematics: MP1, MP3, MP4, MP6, 4.MD.A.2, 4.NBT.A.2, 4.NBT.A.2, 4.NBT.B.4, 5.NBT.B.5, 5.NF.B.4, 5.NF.B.6

Key Terms

engineer, engineering design process, retaining garden, buffer zone, diverting duct, retaining barrier, retaining pool, prototype, model

Lesson Summary

Prior to planning their design, student are exposed to common strategies used to combat runoff pollution. They are then introduced to the design challenge and complete several practice problem to familiarize themselves with the model. Students individually reflect on the information they have learned about pond ecosystems and the criteria and constraints identified by the client to think about possible solutions and explore the available materials to individual create a plan. Finally, students rejoin their team to create a plan to construct a design that prevents chemicals from fertilizers from entering the pond water supply and is environmentally mindful. Students share their designs and results among the class.

Background

Teacher Background

For the past three lessons students have been in the Problem section of the engineering design process, which includes the steps define (the problem) and learn (about the problem). In this lesson, students shift to the Solution section of the engineering process, which includes: plan (the solution), try (the plan of the solution), test (the solution), and decide (whether the solution successfully solves the problem). The focus of this lesson is developing written plans; trying (i.e., implementing or building) the planned solution and testing and evaluating that implemented prototype solution. Students then will repeat the process and redesign. For more information about the engineering design process presented in this unit, see the front matter section about it.

Evidence-based Reasoning: Evidence-based reasoning (EBR) refers to the engineering practice of providing rationale for design ideas and decisions. It is somewhat similar to scientific argumentation in the sense that it involves using evidence and explanations to support a statement, but it is ultimately different. In EBR, the statement being supported is an engineering design idea or decision, whereas in scientific argumentation it is a claim or conclusion about a natural phenomenon. EBR is used in the context of generating solutions for engineering problems; scientific argumentation is used to answer scientific questions about nature. Science and mathematical principles are important justifications for scientific argumentation and EBR. However, EBR often also includes justifications related to the context, criteria, and constraints of the engineering problem (e.g., cost, user needs, technical feasibility). In this lesson, students will use EBR to think deeply about their proposed design ideas and to justify them with information about the engineering problem and their science and mathematics knowledge.

There are many sources of runoff that result in negative effects for various ecosystems. These sources include agricultural, storm water, wastewater, fossil fuels, and products used in and around the home. To address each type of pollution, various solutions have been developed to reduce runoff pollution. Some of these solutions include barriers that hinder and absorb the runoff from entering bodies of water, planting trees and other plants as a buffer to absorb the excess runoff, or building artificial waterways and ponds to divert and capture runoff water. For more information regarding solutions to runoff pollution, visit the Environmental Protection Agency's (EPA) website: https://

www.epa.gov/nutrientpollution/sources-and-solutions-agriculture.

Before the Activity

Print and make copies of the following worksheets in the labeled amounts:

- *4.a. Design Structure Cutouts* (1 per every 2 students)
- *4.c. Design Grid Map* (1 per team + 1 per student)
- *4.d. Design Information* (1 per student)
- *4.e. Practice Problems* (1 per student)
- *4.g. Design Ideas - Individual Plan* (1 per student)
- *4.h. Grid Pieces* (1 per team)
- *4.i. Planning Reflection* (1 per student)
- *4.k. Evidence-Based Reasoning* (1 per team)
- *4.n. Design 1 Plan - Team* (1 per team)
- *4.o. Design Rubric* (1 per team)
- *4.p. Teacher Observation Protocol: Try/Test* (1 per 4 teams)
- *4.q. Design Data* (1 per team)
- *4.r. Test and Evaluate* (1 per student)

(Optional) Cut out the pieces from *4.h. Grid Pieces* and place them into an envelope for each team.

Evidence-Based Reasoning Poster - On one poster size sheet of sticky note paper, draw an Evidence-Based Reasoning template (like *4.m. Evidence-Based Reasoning Instructions - Poster with Explanations*). This poster will contain explanations of the terms on the worksheet and what kind of information goes in each section. Students are not to copy this version. Rather, they are to use it as a guide to help them fill out their own versions of the template.

Cue up the images of the real-world examples of the possible solutions:

- **Retaining wall:** https://commons.wikimedia.org/wiki/File:Retaining_wall_Gravity_Stone.JPG
- **Retaining Garden:** http://s0.geograph.org.uk/geophotos/02/54/73/2547364_4f58ed72.jpg
- **Retaining Pool:** http://www.retentionponds.com/images/gainesville/Gainesville-b.jpg
- **Tree Buffer Zone:** https://upload.wikimedia.org/wikipedia/commons/7/71/Riparian_strip.jpg

Classroom Instruction

Introduction

1. **Review the engineering problem. Say/Ask:** *What was it that our client needed use to help them with?* (To reduce the amount of runoff from the farms so that the population of algae does get too big) *What are some things they need us to consider when designing our solution?* (Minimize cost and limit the impact on pond ecosystem). Have students refer to the *1.b. Client Letter* and the *1.e. Problem Scoping* sheet from lesson 1 if needed.

Assessments

Pre-Activity Assessment
Have the students write a response in their engineering notebook: "What do you think are some ways to prevent runoff?"

Activity Embedded Assessment
While students are planning and trying their designs, walk around to assess their progress using the *4.p. Teacher Observation Protocol: Try/Test* sheet.

Post-Activity Assessment
After team completes *4.n. Design 1 Plan - Team* and the *4.k. Evidence-Based Reasoning* graphic, assess the teams' designs with the *4.l. Evidence-Based Reasoning Rubric*. Assess student responses to *4.r. Test and Evaluate* prompts using the 4.s. *Test and Evaluate Rubric.*

DUPLICATION MASTERS

- 4.a. Design Structure Cutouts
- 4.c. Design Grid Map
- 4.d. Design Information
- 4.e. Practice Problems
- 4.g. Design Ideas - Individual Plan
- 4.h. Grid Pieces
- 4.i. Planning Reflection
- 4.k. Evidence-Based Reasoning
- 4.n. Design 1 Plan - Team
- 4.o. Design Rubric
- 4.q. Design Data
- 4.r. Test and Evaluate

EDUCATOR RESOURCES

- 4.b. Design Structure Rank Example
- 4.f. Practice Problems Answer Key
- 4.j. Planning Reflection Rubric
- 4.l. Evidence-Based Reasoning Rubric
- 4.m. Evidence-Based Reasoning Instructions
- 4.p. Teacher Observation Protocol: Try/Test
- 4.s. Test and Evaluate Rubric

Designing a Solution

Activity

2. **Identify where they are in the engineering design process. (Plan)** Bring the class together to look at the EDP Slider. **Ask:** *Looking at what we are going to do, where do you think we are in the engineering design process?*

3. **Brainstorm ways to prevent runoff.** Have the students write a response in their engineering notebooks to the prompt: *"What do you think are some ways to prevent or reduce runoff?"* Ask students why they think the solutions they came up with will address the issue of runoff.

4. **Connect to real-world solutions.** After the discussion, reveal several real-world solutions to runoff (refer to the EPA's website: https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture). Be sure to emphasize the solutions that the students will use in the design challenge. Show students the images of the real-world examples of the solutions provided the "Before the Activity" section.

5. **Rank each structure's environmental impact.** Pass out *4.a. Design Structure Cutouts* for each group. Have students cut out the pieces and ask them to rank each solution's impact on the environment from the most positive to the least, first individually, then as a group. Have students attach their cut outs (in ranked order) in their engineering notebooks. Have them provide an explanation next to each piece, justifying the environmental impact rank they assigned. An example can be found on *4.b. Design Structure Rank Example*. Some questions that can be asked during this activity are:
   - *Which of these structures are biotic? Abiotic?*
   - *What effect could building __________ have on the local environment?*
   - *How might ____________ affect the ecosystem if it were placed nearby the Horseshoe pond?*

6. **Explain the design grid map.** Pass out a copy of *4.c. Design Grid Map* to each team. Tell them that this is a map of the land in between the farm and pond as described in the client letter. Explain that the text at the top of the columns represents nitrates (N) and phosphates (P) that will flow towards the pond if nothing is done. Each column has 50 lbs of nitrates and 20 lbs of phosphates that run towards the lake. When these numbers are added together across the columns, they equal 300 lbs of nitrates and 120 lbs of phosphates. **Say:** *Your goal is to reduce the runoff pollution to 100 lbs for nitrate and 40 lbs for phosphate.*

7. **Introduce the building structures and the map key.** Pass out a copy of *4.d. Design Information* sheet for each student. Tell them that this sheet contains the possible structures they can build to reduce the amount of nitrate and phosphate in the runoff. Each solution takes up a specific number of grid spaces, has different costs, good (+) or bad (-) impact on the environment, and reduces nitrate and phosphate to varying degrees. Next, direct the students to look at the Map Key and explain what each of these icons mean, using *4.c. Design Grid Map* as a reference. **Ask:** *Why do these have a different impact on the environment?* (i.e. Why do some

have ++, +, -, or - -.)

8. **Work on practice example designs.** Pass out a copy of *4.e. Practice Problems* and go over the examples as a class. Explain how the runoff containing the nitrates and phosphates passes through the buffer zone and in the process, some of the nitrates and phosphates get absorbed or trapped. The runoff that does not get absorbed will flow past the buffer zone and continue to flow downhill. Give the students some time to finish the example problems on their own. They may discuss their answers in their teams afterwards. Monitor the discussions to gauge their understanding, then go over the solutions as a class. NOTE: Pay particular attention to problem #3. This problem shows that placement order does matter.

9. **Connect back to the environment.** Scaffold students' planning of their design by reminding them to consider how their design might impact the local environment. **Ask:** *How might building _________ nearby the ________affect the local ecosystem?* Refer back to the *4.c. Design Grid Map* and the *4.d. Design Information* sheet. Have students discuss in their teams. Use as many or as few examples in order to have students thinking of their impact on the ecosystem.

10. **Generate ideas individually.** Ask students to individually complete the *4.g. Design Ideas - Individual Plan* sheet and insert them into their notebooks. Have students calculate the cost, environmental impact, and remaining nitrate and phosphate for each design. NOTE: Display the images from *4.h. Grid Pieces* so students have an idea about how to draw on their *4.g. Design Ideas - Individual Plan*.

11. **Reflect on individual design ideas.** Pass out *4.i. Planning Reflection* and have students fill in the answer to the first question on the sheet or in their notebooks. Have students look through the ideas they generated and evaluate each of their own idea's pros and cons.

12. **Introduce evidence-based reasoning.** Post an evidence-based reasoning template drawn on a sheet of poster size sticky note paper. Pass out a *4.k. Evidence-Based Reasoning* worksheet to each student or have them draw the EBR template in their notebooks. **Say:** *To help you continue planning your design, we are going to be using evidence-based reasoning. This means that you will need to support your design ideas with evidence and explanations. We will discuss each of the parts together.* Clarify with students that the Evidence-Based Reasoning poster will have general explanations and reminders of what kind of information should go in each section. This is different from what the students will write in the templates. They will fill out the boxes with information specific to their engineering design problem.

13. **Review the problem.** Direct students' attention to the "Problem Including Criteria and Constraints" section of the *4.k. Evidence-Based Reasoning* worksheet and posters. On the poster, write down a general definition of

"problem" (i.e., the problem the client asked you to solve). Instruct students to write a summary of their engineering problem in this section, leaving room for criteria and constraints.

14. **Review the criteria and constraints of the problem. Ask:** *Can anyone remind me what the words "criteria" and "constraints" mean?* Criteria are the requirements, or goals, of the designed solutions. Constraints are things that limit design possibilities. Write these definitions on the Evidence-Based Reasoning poster. **Ask:** *What are some of the criteria and constraints of our engineering problem?* Discuss the criteria and constraints of the problem.

15. **Explain what information goes in each of the remaining sections.** Have students guess at what kind of information they think should go in the "Design Idea," "Data/Evidence," and "Justification" sections of the *Evidence-Based Reasoning* worksheet. Write down relevant student suggestions in the appropriate section of the Evidence-Based Reasoning poster. This could include:
    - **Design Idea:** description of the design idea; drawings of the design idea, possibly with different views (e.g., top view, side view); dimensions/sizes; label materials in the design idea to show where they are used; interesting features of the design idea
    - **Data/Evidence:** Observations and data that show why you think your design will work (examples: data from the Conductor Lab and the Insulator Lab; total cost of the design).
    - **Justification:** Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

16. **Plan as a team.** Have the students share and discuss each of their design ideas as a team. Encourage students to discuss the pros and cons of each design. Based on their discussion, students create one plan for design and fill out *4.n. Design 1 Plan - Team*. As a team, have the students complete a team copy of the *4.k. Evidence-Based Reasoning* sheet based on the design they choose.

17. **Reflect upon design solution.** Looking back at *4.i. Planning Reflection Questions* and have students fill in the answer to the <u>second question</u> on the sheet or in their notebooks. **Say:** *Now that your team has decided upon one design, explain why you chose that design.* Circulate and check students' rationale, making sure it makes sense in the context of the engineering problem.

18. **Consider future work on the engineering design process.** Bring the class together to look at the EDP Slider. **Ask:** *Based on what we have done so far, what stage of the engineering design process will we be at next?* (Try and Test)

19. **Construct the design.** Inform the students to start building their design now. Pass out the *4.h. Grid Pieces* and *4.o. Design Rubric* for each team

and a copy of *4.c. Design Grid Map* for each student. Say that they will construct their design on the team copy of *4.c. Design Grid Map* that was handed out earlier and that their individual copy is for their own use if they need it. Remind the students that their designs must resemble the design their team agreed upon; however, small changes are acceptable (use your judgment).

20. **Assess students as they build their design.** Use the *4.p. Teacher Observation Protocol: Try/Test* sheet to assess students as they try their design. As you walk around, ask students why they placed structures where they did. **Ask:** *How does _(structure)_ affect the local ecosystem?* Check to see if they are connecting their design to science concepts in previous lessons.

21. **Test the design and perform nitrate and phosphate calculations.** After teams are finished constructing their designs, pass out *4.q. Design Data* sheet for each team. Ask student to individually calculate how much phosphate and nitrate are entering the pond using *4.q. Design Data* sheet. After they are done, have them compare their answers with their teammates and discuss any differences you have. After resolving any differences, have them record the team answer on *4.q. Design Data* sheet.

22. **Calculate design cost and environmental impact.** Have each group use *4.q. Design Data* sheet to calculate the impact on the environment and the cost of the design. Students can compare their results to the standards outlined in *4.o. Design Rubric*.

23. **Award bonus environmental points.** As students are performing their calculations, award or subtract points from their environmental score as suggested below. Ask the class to explain why you either awarded or took away points.

Hidden Environmental Points:
- Building a retaining garden adjacent to the turtle nesting grounds: +2 points
- Building a tree buffer zone 1-2 grid spaces from the pond: +1 points
- Building a retaining pool or retaining barrier 1-2 grid spaces from the turtle nesting grounds: -3 points

24. **Tie back to the engineering design process.** After all the groups are finished with their calculations, **ask:** *Thinking about what we just did, where we are at on the Engineering Design Process?* Ask for students to explain their answer.

25. **Analyze results.** Have each student complete the "my response" prompts on *4.r. Test and Evaluate* or in their notebooks. Once everyone in the team has completed the prompts, have them share their responses, discuss, and formulate a group response to the reflection prompt.

26. **Share results with the class.** Have one student per group put their results on a class data table that is posted at the front of the room either on the board or poster paper (see below). Encourage students to explore other teams designs to see how others constructed their design.

Sample Table:

	nitrate remaining	phosphate remaining	environmental score	cost
team 1				
team 2				
team 3				

Closure

27. **Tie back to the engineering design process.** After all the groups have shared their results, **ask:** *Thinking about the activities we just did, can you tell me where those activities would be placed on the Engineering Design Process?* (Decide) Ask for students to explain their answer.

LESSON 4

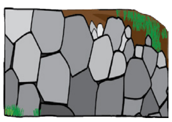
Designing a Solution

LESSON 4

Name________________________________ Date____________ Period _____

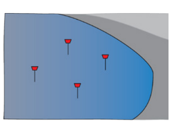
4.a. Design Structure Cutouts

Retaining garden: Contains a mix of plants and flowers that absorbs a small amount of nitrate and phosphates. Provides food for insects and other small animals.

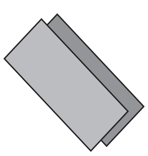


Retaining barrier: Man-made structure that traps runoff. Uses technology to effectively trap phosphates. Construction of this can greatly disrupt habitats.

Tree buffer zone: A field of trees planted that can absorb a lot of nitrate and some phosphate. Prevents loose soil from being washed away. Also provides housing for birds and food for small rodents, but has a high cost.

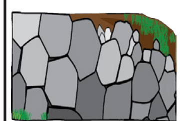


Retaining pool: A large trench built of cement that collects and stores runoff. Requires digging and can disrupt habitats.



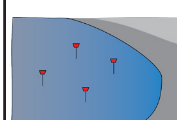
Diverting duct: Concrete structure that diverts water to a different location. Requires some invasive construction and may disrupt habitats.

Retaining garden: Contains a mix of plants and flowers that absorbs a small amount of nitrate and phosphates. Provides food for insects and other small animals.

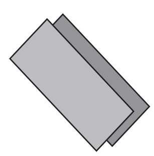


Retaining barrier: Man-made structure that traps runoff. Uses technology to effectively trap phosphates. Construction of this can greatly disrupt habitats.

Tree buffer zone: A field of trees planted that can absorb a lot of nitrate and some phosphate. Prevents loose soil from being washed away. Also provides housing for birds and food for small rodents, but has a high cost.



Retaining pool: A large trench built of cement that collects and stores runoff. Requires digging and can disrupt habitats.



Diverting duct: Concrete structure that diverts water to a different location. Requires some invasive construction and may disrupt habitats.

4.b. Design Structure Rank Example

Tree buffer zone: A field of trees planted that can absorb a lot of nitrate and some phosphate. Prevents loose soil from being washed away. Also provides housing for birds and food for small rodents, but has a high cost.

We ranked this the most environmentally friendly because...

____

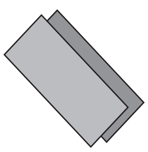
____

Retaining garden: Contains a mix of plants and flowers that absorbs a small amount of nitrate and phosphates. Provides food for insects and other small animals.

We ranked this the second most environmentally friendly because...

____

____



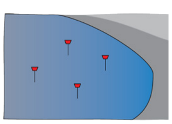
Diverting duct: Concrete structure that diverts water to a different location. Requires some invasive construction and may disrupt habitats.

The diverting duct is in the middle because...

____

____

____

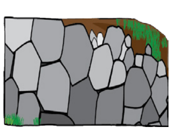


Retaining pool: A large trench built of cement that collects and stores runoff. Requires digging and can disrupt habitats.

We ranked this above the retaining barrier because...

____

____



Retaining barrier: Man-made structure that traps runoff. Uses technology to effectively trap phosphates. Construction of this can greatly disrupt habitats.

We ranked this as the least environmentally friendly because...

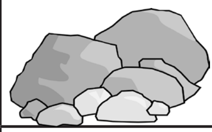
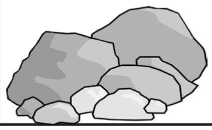
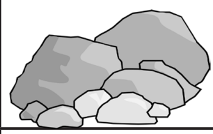
____

____

LESSON 4

Name________________________________ Date____________ Period ______

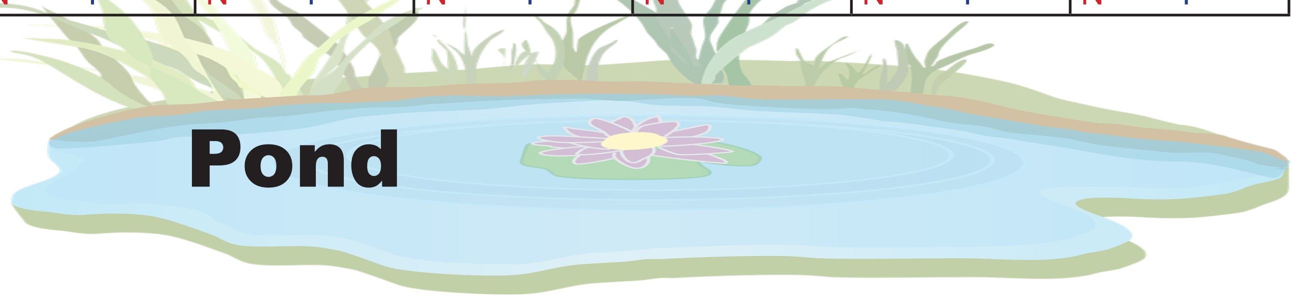
4.c. Design Grid Map

50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =

Total:
300 lbs. N
120 lbs. P

water flow

Goal:
≤ 100 lbs. N
≤ 40 lbs. P



LESSON 4

Name________________________________ Date____________ Period _____

4.d. Design Information

Retaining garden: Contains a mix of plants and flowers that absorbs a small amount of nitrate and phosphates. Provides food for insects and other small animals.

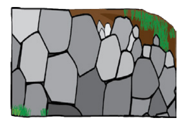
Grid Space: 1 ☐

Nitrate Reduction: 10 lbs.

Phosphate Reduction: 2 lbs.

Cost: $4000

Environmental Impact: 



Retaining barrier: Man-made structure that traps runoff. Uses technology to effectively trap phosphates. Construction of this can greatly disrupt habitats.

Grid Space: 3 ☐☐☐

Nitrate Reduction: 15 lbs.

Phosphate Reduction: Reduces by ½

Cost: $10,000

Environmental Impact: 

Tree buffer zone: A field of trees planted that can absorb a lot of nitrate and some phosphate. Prevents loose soil from being washed away. Also provides housing for birds and food for small rodents, but has a high cost.

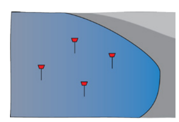
Grid Space: 2 ☐☐

Nitrate Reduction: Reduces by ½

Phosphate Reduction: 4 lbs.

Cost: $9000

Environmental Impact: 



Retaining pool: A large trench built of cement that collects and stores runoff. Requires digging and can disrupt habitats.

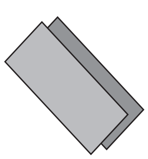
Grid Space: 2 ☐☐

Nitrate Reduction: 8 lbs.

Phosphate Reduction: 6 lbs.

Cost: $6000

Environmental Impact: 



Diverting duct: Concrete structure that diverts water to a different location. Requires some invasive construction and may disrupt habitats. Must be built 1 grid space uphill from other structures.

Grid Space: 1 ☐

Diverts phosphate and nitrate to next column

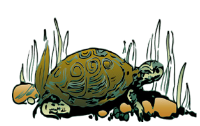
Cost: $2000

Environmental Impact: 

Map Key

Landmark: No construction allowed in this area.

Cabins: People frequently visit to explore to see the pond. No construction allowed.



Turtle nesting grounds: Eggs are often found in this area.

Proximity line: Environmental impact doubles below this line.

LESSON 4

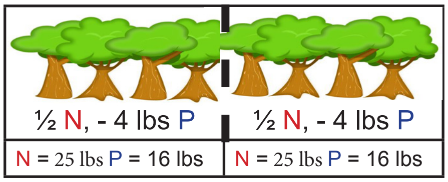
Name________________________________ Date____________ Period _____

4.e. Practice Problems (1/2)

Examples:

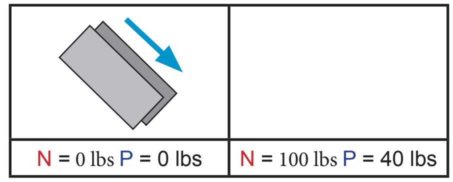
1. Tree buffer zone reduces passing nitrates by ½ and reduces phosphates by 4 lbs.

50 lbs. N 50 lbs. N
20 lbs. P 20 lbs. P



2. The diverting duct moves water to the right, along with the nitrate and phosphate. The amount of nitrate and phosphate are added together.

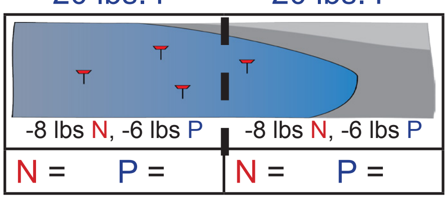
50 lbs. N 50 lbs. N
20 lbs. P 20 lbs. P



Problems:

1.

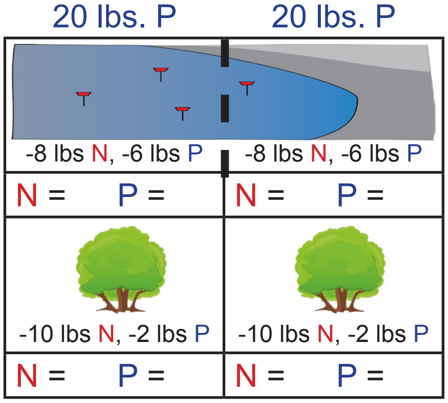
Column 1 Column 2
50 lbs. N 50 lbs. N
20 lbs. P 20 lbs. P



	Column 1		Column 2	
	N	P	N	P
starting values				
retaining pool removal				
amount remaining				

2.

Column 1 Column 2
50 lbs. N 50 lbs. N
20 lbs. P 20 lbs. P

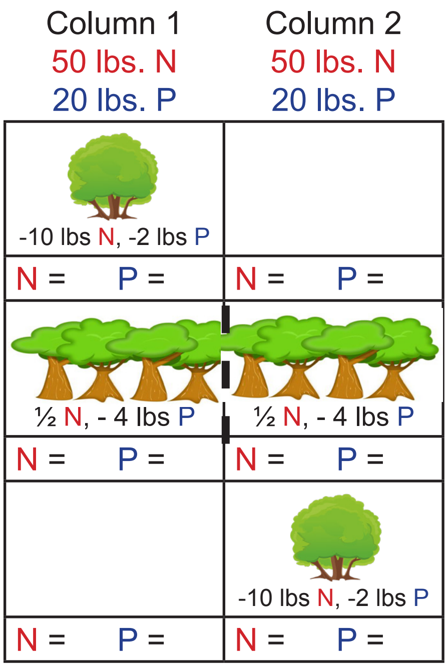


	Column 1		Column 2	
	N	P	N	P
starting values				
retaining pool removal				
amount remaining				
retaining garden removal				
amount remaining				

Name________________________________ Date____________ Period ______

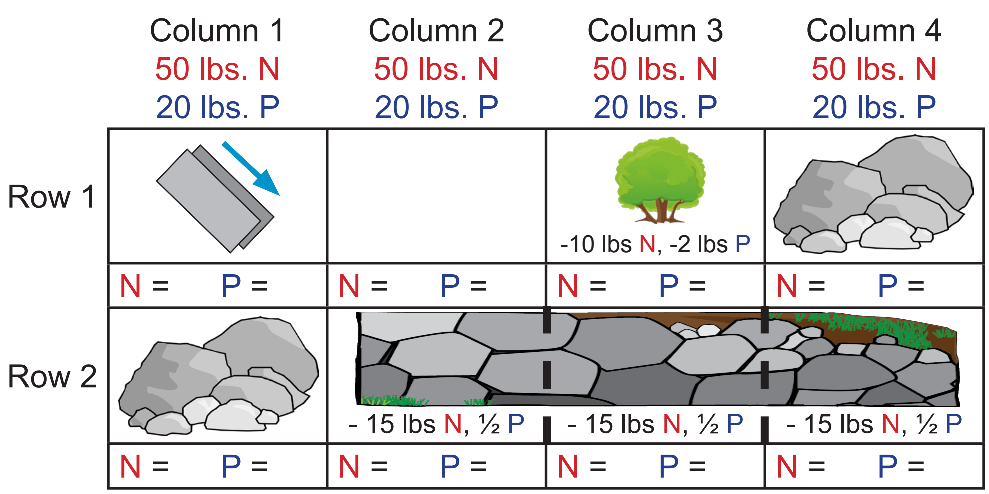
LESSON 4 — 4.e. Practice Problems (2/2)

3.



	Column 1		Column 2	
	N	P	N	P
starting values				
retaining garden removal			/	/
amount remaining				
tree buffer zone removal				
amount remaining				
retaining garden removal	/	/		
amount remaining				

4.

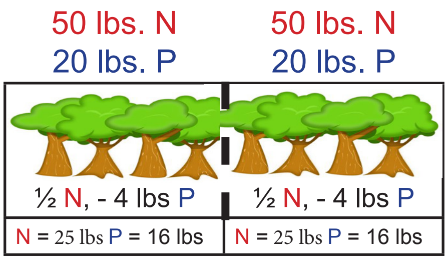


	Column 1		Column 2		Column 3		Column 4	
	N	P	N	P	N	P	N	P
starting values								
row 1								
amount remaining								
row 2								
amount remaining								

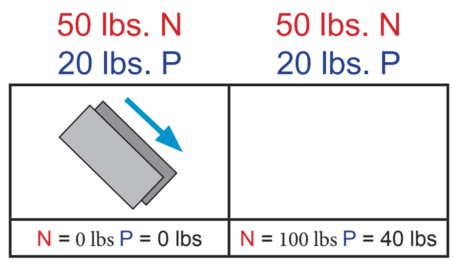
4.f. Practice Problems Answer Key

Examples:

1. Tree buffer zone reduces passing nitrates by ½ and reduces phosphates by 4 lbs.

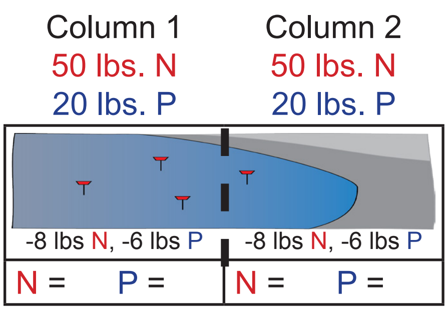


2. The diverting duct moves water to the right, along with the nitrate and phosphate. The amount of nitrate and phosphate are added together.



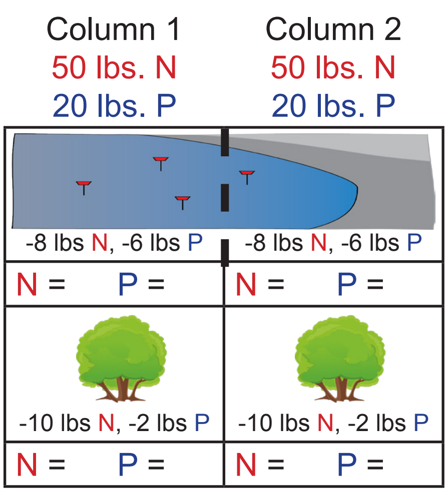
Problems:

1.



	Column 1		Column 2	
	N	P	N	P
starting values	50	20	50	20
retaining pool removal	-8	-6	-8	-6
amount remaining	42	14	42	14

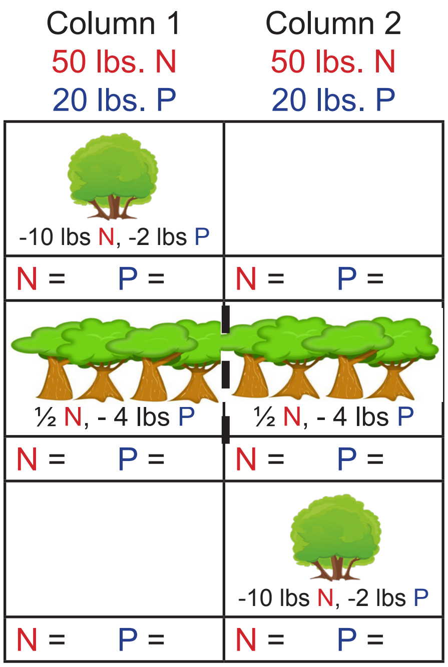
2.



	Column 1		Column 2	
	N	P	N	P
starting values	50	20	20	50
retaining pool removal	-8	-6	-8	-6
amount remaining	42	14	42	14
retaining garden removal	-10	-2	-10	-2
amount remaining	32	12	32	12

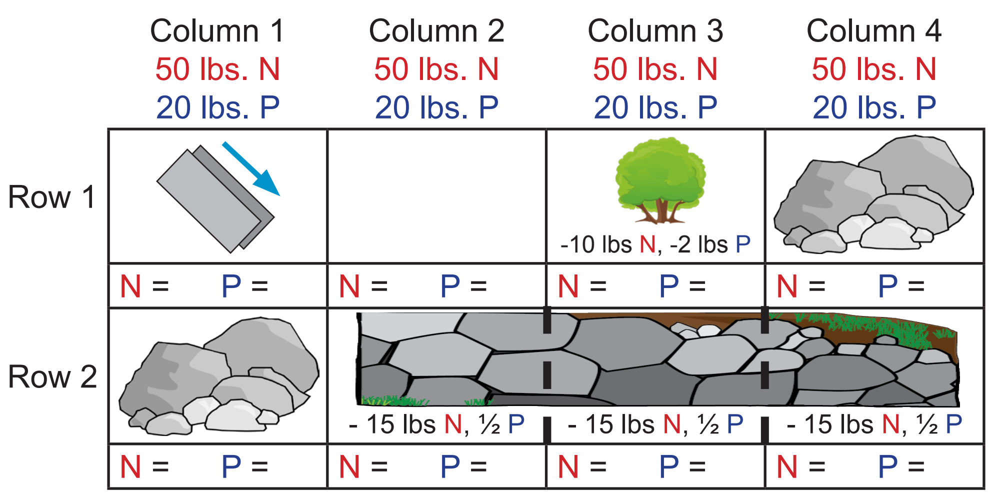
4.f. Practice Problems Answer Key

3.



	Column 1		Column 2	
	N	P	N	P
starting values	50	20	50	20
retaining garden removal	-10	-2		
amount remaining	40	18	50	20
tree buffer zone removal	½	-4	½	-4
amount remaining	20	14	25	16
retaining garden removal			-10	-2
amount remaining	20	14	15	14

4.



	Column 1		Column 2		Column 3		Column 4	
	N	P	N	P	N	P	N	P
starting values	50	20	50	20	50	20	50	20
row 1	-50	-20	+50	+20	-10	-2	0	0
amount remaining	0	0	100	40	40	18	50	20
row 2	-	-	-15	½	-15	½	-15	½
amount remaining	0	0	85	20	25	9	35	10

Name_______________________________ Date___________ Period ______

LESSON 4

4.g. Design Ideas - Individual Plan

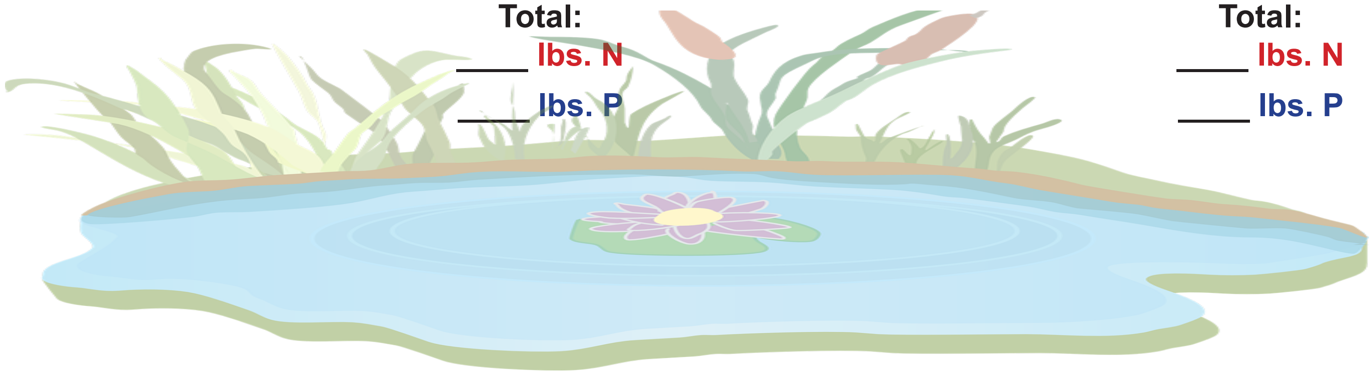
Directions: Try to reduce the amount of phosphate and nitrate flowing down using two different designs. Be sure to show your work. NOTE: For this exercise, the retaining wall can be placed outside the grid.

50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	Total: 100 lbs. N 40 lbs. P
N = P =	N = P =	water flow
N = P =	N = P =	
N = P =	N = P =	
N = P =	N = P =	
N = P =	N = P =	
N = P =	N = P =	

Total:
____ **lbs. N**
____ **lbs. P**

50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	Total: 100 lbs. N 40 lbs. P
N = P =	N = P =	water flow
N = P =	N = P =	
N = P =	N = P =	
N = P =	N = P =	
N = P =	N = P =	
N = P =	N = P =	

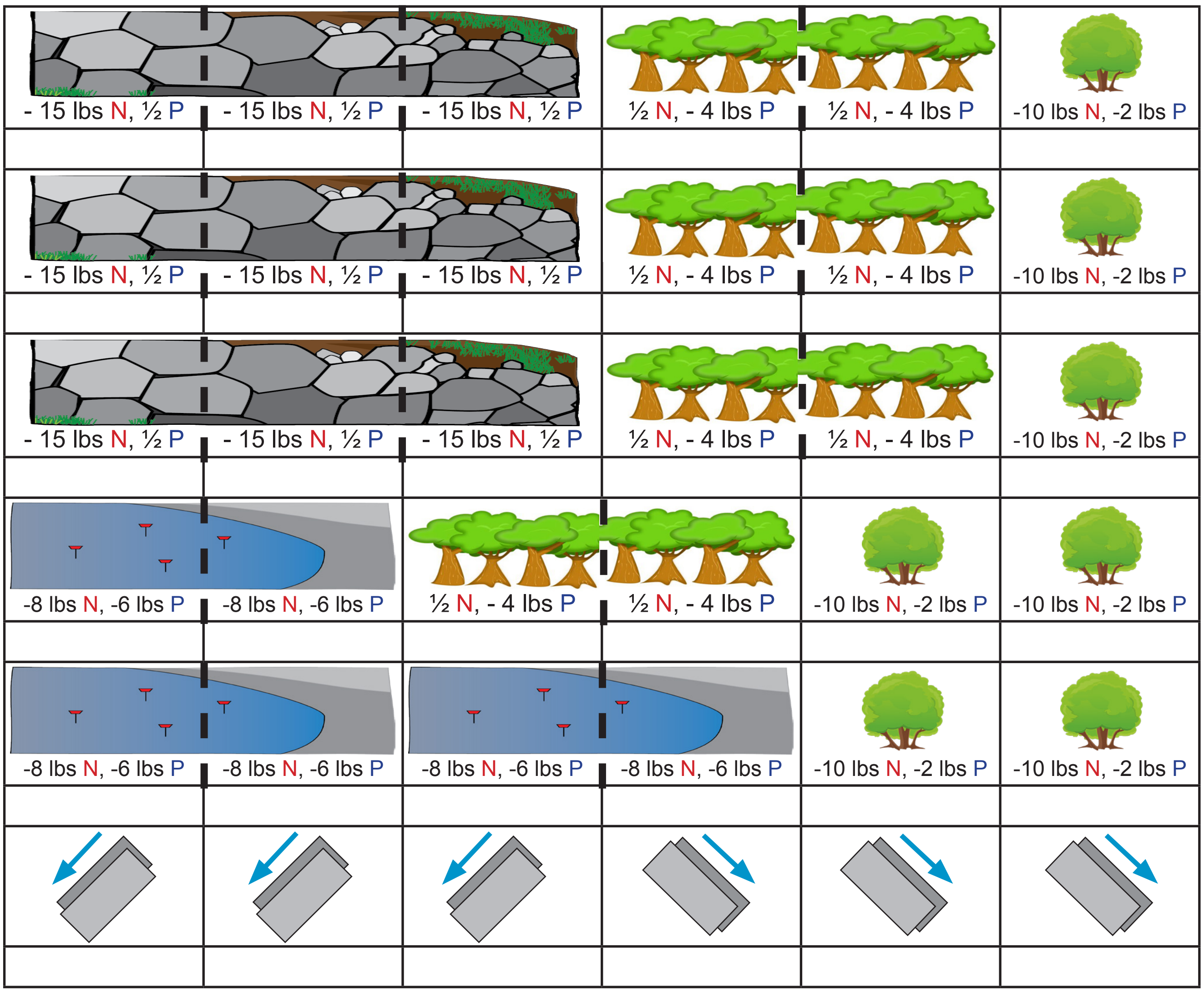
Total:
____ **lbs. N**
____ **lbs. P**



LESSON 4

Name____ Date_____________ Period ______

4.h. Grid Pieces



LESSON 4

Name________________________________ Date____________ Period _____

4.i. Planning Reflection

1. What are the pros and cons of each of your own solution ideas?

2. Which solution did your team choose and why? Provide evidence for your reason.

LESSON 4

Name______________________ Date__________ Period _____

4.j. Planning Reflection Rubric

Problem	Question	Learning Objectives	Rubric	
4.i.1	What are the pros and cons of each of your own solution ideas?	Select potential solution through systematic evaluation of various solutions based on the problem.	yes no	**Provided at least 1 pro for each solution generated (as an individual)**
			yes no	**Provided at least 1 con for each solution generated (as an individual)**
4.i.2	Which solution did your team choose and why? Provide evidence for your reason.	Select potential solution through systematic evaluation of various solutions based on the problem.	yes no	**Stated which solution was chosen**
			yes no	**Provided an explanation for why the team chose that solution that was based on evidence**

Notes:

LESSON 4

Name________________________________ Date____________ Period ______

4.k. Evidence-Based Reasoning (1/2)

Problem with Criteria & Constraints • Explain the client's problem that needs a solution and why it is important to solve. • List criteria and constraints you will use to decide if your solution is working.
Problem: ______________________________ ______________________________ **Criteria:** ______________________________ **Constraints:** ______________________________
Simplifying Assumptions • List things that might be important but you have decided not to worry about.
______________________________ ______________________________

Description of Design Idea • Provide a description of your design idea including why you made these design choices.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.
See 4.i. Design 1 Plan - Team for Image ______________________________	______________________________

LESSON 4

Name_________________________ Date___________ Period _____

4.k. Evidence-Based Reasoning (2/2)

Justification - Why do you think this design idea will work?

- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

Student Name______________________________ Date__________ Period _____

4.I. Evidence-Based Reasoning Rubric

Section	Learning Objective	Rubric	
Problem	Explain the problem based on a synthesis of information. Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Identified problem**
		yes no	**Explained why the problem is important**
Criteria	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
Constraints	Explain constraints based on information.	yes no	**Identified at least 1 constraint**
Simplifying Assumptions	Explain assumptions they have made in order to make solving the problem more manageable.	yes no	**Identified at least 1 simplifying assumption**
Design Idea	Communicate design idea through drawing, including labels for materials and function of parts.	yes no	**Included drawing to represent design idea**
		yes no	**Included labels of materials**
		yes no	**Included labels of what each part does**
Data/Evidence (List math/science learned and/or results of tests that support your design idea)	Apply evidence gathered from testing to choose solution. Apply math/science concepts to choose solution.	yes no	**Listed at least 1 piece of valid evidence**
		yes no	**Evidence is from mathematics/science they have learned or from the results of the tests**
Justification (Explain how your data/evidence supports your design idea in order to meet criteria/constraints. Why do you think this will work?)	Justify why their design solution is appropriate based on application of core science/ mathematics concepts Justify why their design solution is appropriate based on information obtained in problem scoping.	yes no	**Included explanation of how their data/ evidence supports their design idea**
		yes no	**Explained why this will work**
		yes no	**Explained how design idea will meet criteria/constraints**
Notes:			

4.m. Evidence-Based Reasoning Instructions

Poster with Explanation

Problem with Criteria & Constraints
- Explain the client's problem that needs a solution and why it is important to solve.
- List criteria and constraints you will use to decide if your solution is working.

Problem: **the engineering problem the client asked you to solve**

Criteria: **the requirements, or goals, of the designed solutions**

Constraints: **things that limit design possibilities**

Simplifying Assumptions
- List things that might be important but you have decided not to worry about.

Ways to make a complex problem simpler.

Description of Design Idea • Provide a description of your design idea.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.
• **Drawings of the design (which is done on sheet 4.i.)** ◦ **Labels or pictures of structures in design (show where they are used)** • **Description of the design** • **Why decisions were made** • **Interesting features**	**Observations and data that show why you think your design will work** **Examples:** • **Data from science and mathematics lessons, labs, and activities** • **Theoretical science/mathematics that provide reasons for choices they made** • **Total cost of design**

Justification - Why do you think this design idea will work?
- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

Complete sentences that state why it is possible that the design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

4.m. Evidence-Based Reasoning Instructions

Pollutants in the Pond Example

Problem with Criteria & Constraints
- Explain the client's problem that needs a solution and why it is important to solve.
- List criteria and constraints you will use to decide if your solution is working.

Problem: Runoff pollution is entering the nearby pond.
Criteria: The design must reduce the amount of nitrate and phosphate entering the pond and be environmentally friendly.
Constraints: The design must not exceed the client's budget of $65,000.

Simplifying Assumptions
- List things that might be important but you have decided not to worry about.

We do not need to worry about the water itself.

Description of Design Idea	Data/Evidence
• Provide a description of your design idea.	• List science/mathematics learned and/or results of tests that support your design idea.
• Drawings of the design (which is done on sheet 4.i.) • Labels or pictures of structures in design (show where they are used) • Description of the design • Why decisions were made • Interesting features	• We will use 2 retaining walls because of its ability to greatly reduce phosphate. • We will build several tree buffer zones below the proximity line to have a more positive environmental impact. These will provide food and shelter to animals of the ecosystem.

Justification - Why do you think this design idea will work?
- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

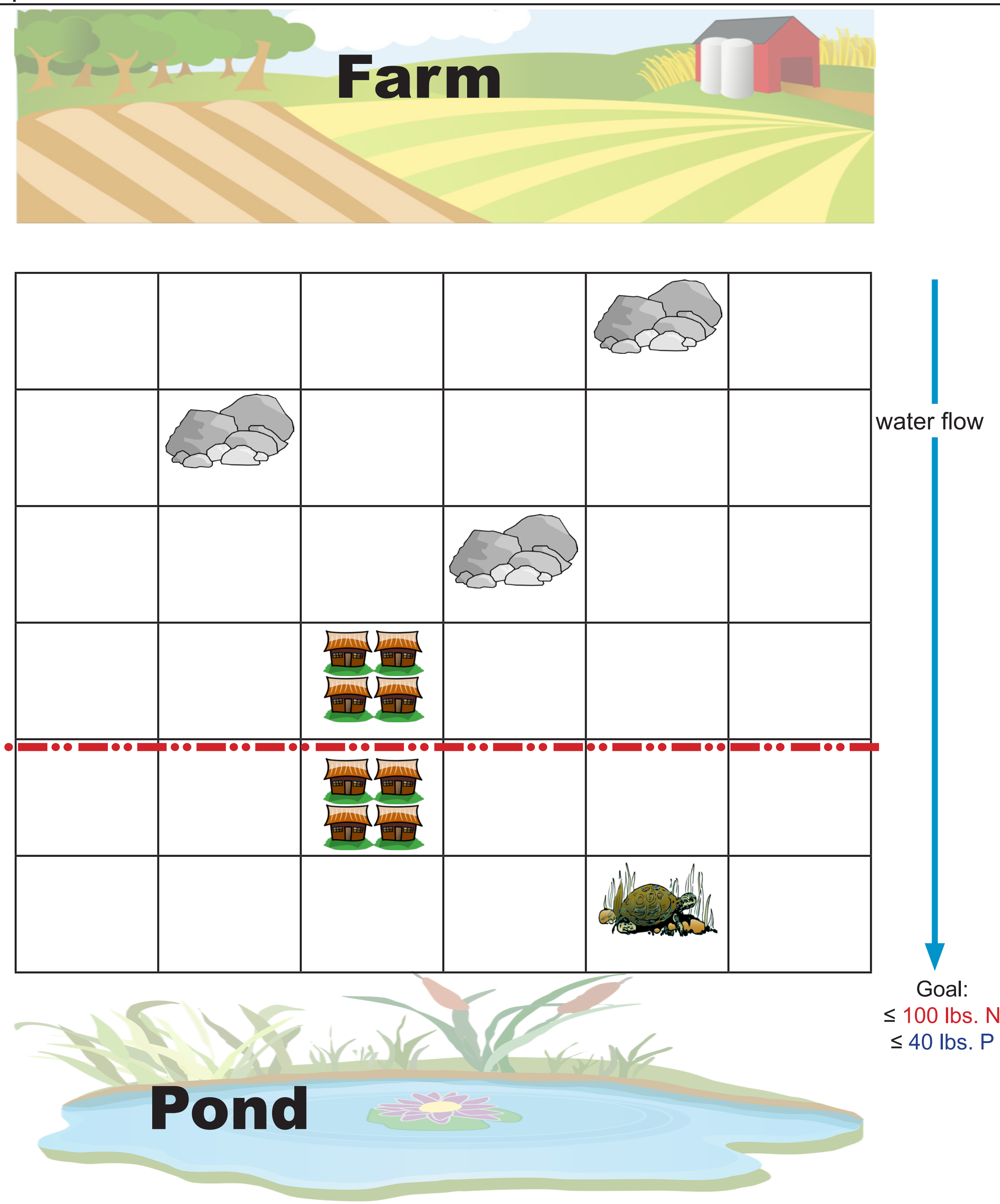
We will be using both biotic and abiotic solutions to reduce the phosphate and nitrate levels. Our planned design might have a high cost because we added a lot of expensive structures like the tree buffer zone, but the design is more environmentally friendly.

LESSON 4

Engineers on Team____

4.n. Design 1 Plan - Team

Design Idea: Sketch and label a layout that you think will solve the client's problem on the map below.



LESSON 4

Name________________________________ Date___________ Period _____

4.o. Design Rubric

Criteria/Constraints	Exceeds Criteria/ Constraints	Meets Criteria/ Constraints	Needs Work
Amount of Nitrate	≤ 80 lbs.	≤ 100 lbs.	> 100 lbs.
Amount of Phosphate	≤ 30 lbs.	≤ 40 lbs.	> 40 lbs.
Cost	< $55,000	≤ $60,000	> $60,000
Environmental Score	≥ 10 points	≥ 5 points	< 5 points

LESSON 4

Name________________________________ Date___________ Period _____

4.o. Design Rubric

Criteria/Constraints	Exceeds Criteria/ Constraints	Meets Criteria/ Constraints	Needs Work
Amount of Nitrate	≤ 80 lbs.	≤ 100 lbs.	> 100 lbs.
Amount of Phosphate	≤ 30 lbs.	≤ 40 lbs.	> 40 lbs.
Cost	< $55,000	≤ $60,000	> $60,000
Environmental Score	≥ 10 points	≥ 5 points	< 5 points

96 Pollutants in the Pond FT
EngrTEAMS © 2017 University of Minnesota & Purdue University Research Foundation

4.p. Teacher Observation Protocol: Try/Test

Team	All team members are on-task to try their solution.	One or more team members are not on-task.	Team has made appropriate progress on their solution.	Team is struggling to make their solution.	Team is making a solution directly related to problem.	Team is making something unrelated to problem.	Team has made appropriate progress on testing and analysis.	Team is struggling to test or analyze their solution.	Team has identified how to improve solution.	Team is struggling to consider improved performance.

Team ________ Notes:	Team ________ Notes:	Team ________ Notes:	Team ________ Notes:

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. Can you tell me about your solution? What are you designing?
2. What were some of the other solution ideas you generated? How well did they address the problem?
3. How did you decide to move forward with this idea? What evidence do you have that your design will solve the problem for the client?

LESSON 4

Name________________________________ Date____________ Period _____

4.q. Design Data

Total nitrate and phosphate:

Fill in the amount of nitrate and phosphate that entered the pond from each column.

	column						
	1	2	3	4	5	6	total
nitrate							
phosphate							

Environmental impact:

structure	impact	amount used above the proximity line	amount used below the proximity line (multiply impact by 2)	total impact
retaining garden	+			
tree buffer zone	+++			
diverting duct	-			
retaining barrier	----			
retaining pool	--			

Environmental score:

______________ - ______________ = ______________________

(total +) (total -) environmental score

Material costs:

structure	amount used	price per unit	cost
retaining garden		$4,000	
tree buffer zone		$9,000	
diverting duct		$2,000	
retaining barrier		$10,000	
retaining pool		$6,000	
		total cost:	

LESSON 4

Name________________________________ Date___________ Period _____

4.r. Test and Evaluate (1/2)

Section 1

Directions: Please answer the following questions about what you learned from testing.

1. What are the results of your test(s)? Provide a short summary.

2. What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work.

My response:

Team response:

3. What changes will you make to improve your solution based on the results of your tests?

My response:

Team response:

Name________________________________ Date___________ Period _____

4.r. Test and Evaluate (2/2)

4. Why will you make those changes? Think about the results of your test and the science and mathematics you have learned.

My response:

Team response:

Section 2

Directions: Please answer the following questions about the overall quality of your solution.

5. In what ways does your solution meet the criteria and constraints of the problem?

My response:

Team response:

6. In what ways does your solution not yet meet the criteria and constraints of the problem?

My response:

Team response:

LESSON 4

Student Name___________________________________ Date___________ Period _____

4.s. Test and Evaluate Rubric

Problem	Question	Learning Objectives	Rubric	
4.r.1	What were the results of your test(s)?	Analyze test results.	yes no	**Listed specific results of tests**
4.r.2-4	2. What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work. 3. What changes will you make to your solution based on the results of your tests? 4. Why will you make those changes? Think about the results of your tests and the mathematics and science you have learned.	Analyze test results. Apply evidence gathered through test analysis to improve the performance of chosen solution. Apply evidence gathered from testing to choose solution. Apply mathematics/science concepts to inform redesign.	yes no	**Explained advantages of solution found in tests**
			yes no	**Explained drawbacks of solution found in tests**
			yes no	**Listed planned improvements**
			yes no	**Explained rationale for improvements based on test results**
			yes no	**Explained rationale for improvements based on correct understanding of mathematics/ science**
4.r.5	In what ways does your solution meet criteria and constraints of the problem?	Evaluate the alignment between their proposed solution and the problem.	yes no	**Compared their solution to specified criteria and constraints**
4.r.6	In what ways does your solution not yet meet the criteria and constraints of the problem?	Evaluate the alignment between their proposed solution and the problem.	yes no	**Contrasted their solution to specified criteria and constraints**

Notes:

LESSON 5 Redesigning a Solution

Lesson Objectives
Students will be able to:
- evaluate their first prototype based on their initial testing.
- redesign their solutions based on their first design.
- apply science and mathematics to inform the redesign.
- build and test their second prototype.

Time Required
Two 50-minute class periods

Materials
Per classroom:
- chart paper
- 1 EDP Poster

Per team:
- scissors
- glue stick

Per student:
- 1 pen
- 1 Engineering Notebook
- 1 EDP slider & paper clip

Standards Addressed
- Next Generation Science Standards: 3-5-ETS1-B, 3-5-ETS1-C
- Common Core State Standards – Mathematics: MP1, MP3, MP4, MP6, 4.MD.A.2, 4.NBT.A.2, 4.NBT.A.2, 4.NBT.B.4, 5.NBT.B.5, 5.NF.B.4, 5.NF.B.6

Key Terms
redesign

Lesson Summary
Students reflect upon their first design and then construct a new solution based on their data and observations. Students then build and retest their new design to better fit the client's criteria and constraints. After testing and calculating their results, the students use their data to justify the effectiveness of their design. Students record and share their results and consider which of their two designs best fit the client's request.

Background
Teacher Background
Learning from failure: One of the most important aspects of engineering is learning from failure. Engineers often purposefully test models and prototypes until failure in order to better understand the limits of their designs. The engineers then use what they learned from this failure to redesign. Thus, in the engineering design process, it is important to continue beyond the first design cycle.

Redesign: After analyzing and evaluating their first prototype, students will begin to identify potential problems in the design, construction, organization, or cost of the original. At this point, some students will want to leap into a new design, others will insist on the success of their first prototype, while others may want to give up. The teacher can be a key factor in encouraging and guiding students through this transitional time. Because some students may be overly eager and want to skip the plan step of redesign, remind them of the importance of thinking through a design and creating written plans. For teams who are satisfied with their initial design's performance, encourage them to create a design that improves performance. For all teams, especially those who may want to give up, remind them that failing and then redesign is a key part of engineering and what professional engineers do. This is the stage in which students' understanding and skills are deepened and strengthened as they struggle with challenges and decisions. Learning from failure is not just an important skill for engineering, but it is also an important life skill. For redesign, encourage student teams that did not meet the main criteria to focus on meeting those criteria in their redesign. For teams that did meet the main criteria, encourage them to improve their design. Additionally, teams can think about other features that came up during defining the problem or testing the solution.

The main role of the teacher during this lesson will be checking in on student teams and scaffolding discussion around the environmental impact of their designs. Since students have reflected on this aspect on their first design, probe deeper into their design and explore the how their design may indirectly affect organisms.

Before the Activity
Print and make copies of the following worksheets in the labeled amounts:
- *4.h. Grid Pieces* (1 per team)
- *5.a. Design 2 Plan - Team* (1 per team)
- *5.b. Redesign: Evidence-Based Reasoning* (1 per team)
- *5.e. Redesign Grid Map* (1 per team)

- *5.f. Redesign Data* (1 per team)
- *5.g. Redesign Rubric* (1 per team)
- *5.h. Teacher Observation Protocol: Redesign* (1 per 4 teams)
- **(Optional)** *4.p. Teacher Observation Protocol: Try/Test*

(Optional) Cut out the pieces from *4.h. Grid Pieces* and place them into an envelope for each team.

Classroom Instruction

Introduction

1. **Introduce activity for the day and tie to the engineering design process.** Inform the students that they will be planning and building their redesign. **Ask:** *Why do engineers redesign their prototypes? Can you tell me where our next activities are in the Engineering Design Process?* (Plan)

2. **Recall testing from the previous day.** As a class, have the students share about their experiences from planning and testing their first design. This will allow groups to draw upon other group's ideas and incorporate them into their design. **Ask:**
   - *What worked well?*
   - *What are you considering changing? Why?*
   - *If you succeeded in meeting the client's criteria and constraints, what can you do to improve the design to better meet the client's needs?*

Activity

3. **Connect back to the environment.** Scaffold students' planning of their design by asking them to think about how certain structures placed in various areas might indirectly harm or benefit organisms in the ecosystem. Have students discuss in their groups. Afterwards, have a class discussion how their design choices have distant effects, particularly focusing on food webs and food chains.

4. **Remind students of the end user.** Ask if any team built an abiotic structure nearby the cabins. **Say:** *How do you think the people who visit those cabins feel about your decision to build a retaining pool/ barrier there?* Have students discuss what they think and why placing these abiotic structures near the cabins might be a poor choice when considering the end-user.

5. **Prepare for the redesign**. Remind students that they have copies of the *4.d. Design Information* sheet and *4.c. Design Grid Map* in their notebooks. Have the students get back in their teams and discuss their thoughts about their redesign. Remind the class that the data and information from when they did their first team copy of the *4.n. Design 1 Plan - Team* and *4.k. Evidence-Based Reasoning* graphic is still relevant. Emphasize that since they have tested their first design, they now have even more evidence and data to inform their choices on the redesign.

6. **Plan the redesigned solutions.** Teams will work together to complete a team copy of the *5.a. Design 2 Plan - Team* and the *5.b. Redesign:*

Assessments

Pre-Activity Assessment
Monitor student reflection to the prompt, "Why is it important for engineers to redesign and retest their designs?" in their engineering notebooks.

Activity Embedded Assessment
Monitor student work on the team copy of *5.a. Design 2 Plan - Team* and the *5.b. Redesign: Evidence-Based Reasoning* for their redesign. While students are constructing their design, walk around to each team and assess their progress with the *5.h. Teacher Observation Protocol: Redesign* sheet. Students will use notebook prompts on testing as reflection.

Post-Activity Assessment
Use the *5.c. Redesign: Evidence-Based Reasoning Rubric* to assess the redesigned solutions. Assess student reflection on which of their two designs they thought was better. Specifically, look for evidence and justifications to support their choice.

DUPLICATION MASTERS

- 5.a. Design 2 Plan - Team
- 5.b. Redesign: Evidence-Based Reasoning
- 5.e. Redesign Grid Map
- 5.f. Redesign Data
- 5.g. Redesign Rubric

EDUCATOR RESOURCES

- 5.c. Redesign: Evidence-Based Reasoning Rubric
- 5.d. Redesign: EBR Instructions
- 5.h. Teacher Observation Protocol: Redesign

Evidence-Based Reasoning. **Say:** *Remember that the evidence-based reasoning graphic is essential to helping you complete a redesign plan that uses informed design choices.* Circulate and prompt the groups with questions about why they are making their design choices. Inform students that their final design must resemble what they draw on their planning sheet. NOTE: 5.d. Redesign: EBR Instructions provides an example of a completed graphic.

7. **Tie back to engineering design process.** After the students have finished their redesign plans, bring the class together to look at the EDP Slider. **Ask:** *Based on what we have done so far today, what stage of the engineering design process will we be at next?* (Try and Test)

8. **Give directions for constructing their redesign.** Have students start to construct their redesign using the *4.f. Grid Pieces* and the *5.e. Redesign Grid Map*. Teams will build the design according to what they sketched on their *5.a. Design 2 Plan - Team* sheet. Again, minor changes are acceptable.

9. **(Optional) Assess students as they build.** Use the *4.p. Teacher Observation Protocol: Try/Test* sheet to assess students as they construct their redesign.

10. **Test the redesign.** After teams are finished constructing their designs, have students calculate and record how much phosphate and nitrate are entering the pond using *5.f. Redesign Data* sheet, first individually, then as a group. Additionally, have them calculate the environmental impact and the design cost. Students can compare their results to the standards outlined in *5.g. Redesign Rubric*.

11. **Review the redesigned solution.** After students indicate that they are finished building their redesign, check to see that their new design resembles what they sketched previously and record on *5.h. Teacher Observation Protocol: Redesign.*

Closure

12. **Reflect on the two designs.** Have the students write individual exit slips on a sticky note that states which of their two designs they think best suited their client's needs and why.

LESSON 5

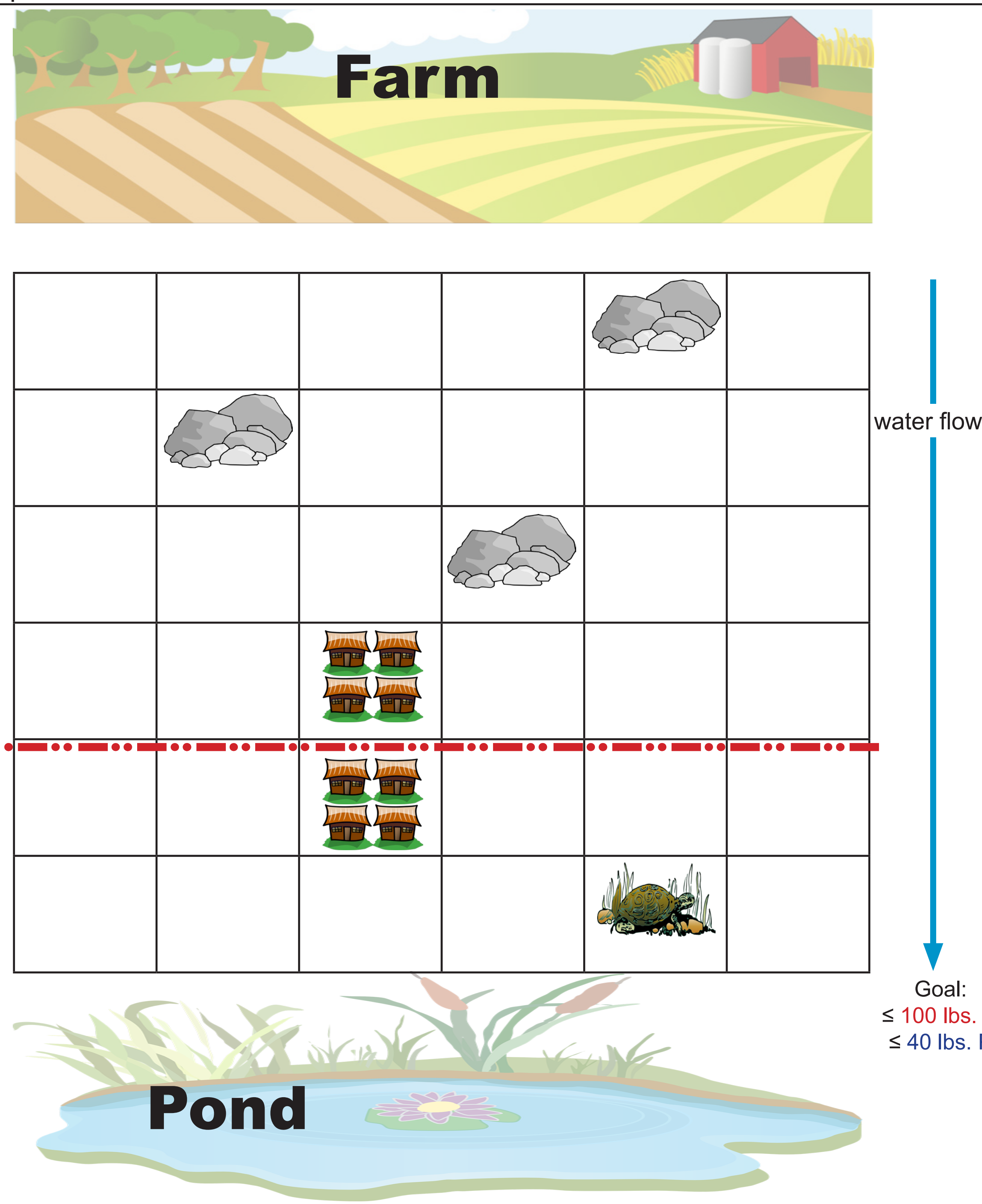
Redesigning a Solution

LESSON 4

Engineers on Team____

5.a. Design 2 Plan - Team

Design Idea: Sketch and label a layout that you think will solve the client's problem on the map below.



Goal:
≤ 100 lbs. N
≤ 40 lbs. P

Name________________________________ Date__________ Period _____

5.b. Redesign: Evidence-Based Reasoning (1/2)

Problem with Criteria & Constraints
- Explain the client's problem that needs a solution and why it is important to solve.
- List criteria and constraints you will use to decide if your solution is working.

Problem: ____

____

Criteria: ____

Constraints: ____

Simplifying Assumptions
- List things that might be important but you have decided not to worry about.

____

____

Description of Design Idea • Provide a description of your design idea.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.
See 5.a. Design 2 Plan - Team for Image	

LESSON 5

Name______________________________ Date____________ Period ______

5.b. Redesign: Evidence-Based Reasoning (2/2)

Justification - Why do you think this design idea will work?

- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

LESSON 5

Student Name_________________________________ Date___________ Period _____

5.c. Redesign: Evidence-Based Reasoning Rubric

Section	Learning Objective	Rubric	
Problem	Explain the problem based on a synthesis of information. Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Identified problem**
		yes no	**Explained why the problem is important**
Criteria	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
Constraints	Explain constraints based on information.	yes no	**Identified at least 1 constraint**
Simplifying Assumptions	Explain assumptions they have made in order to make solving the problem more manageable.	yes no	**Identified at least 1 simplifying assumption**
Design Idea	Communicate design idea through drawing, including labels for materials and function of parts.	yes no	**Included drawing to represent design idea**
		yes no	**Included labels of materials**
		yes no	**Included labels of what each part does**
Data/Evidence (List math/science learned and/or results of tests that support your design idea)	Apply evidence gathered from testing to choose solution. Apply math/science concepts to choose solution.	yes no	**Listed at least 1 piece of valid evidence**
		yes no	**Evidence is from mathematics/science they have learned or from the results of the tests**
Justification (Explain how your data/evidence supports your design idea in order to meet criteria/constraints. Why do you think this will work?)	Justify why their design solution is appropriate based on application of core science/ mathematics concepts. Justify why their design solution is appropriate based on information obtained in problem scoping.	yes no	**Included explanation of how their data/ evidence supports their design idea**
		yes no	**Explained why this will work**
		yes no	**Explained how design idea will meet criteria/constraints**
Notes:			

5.d. Redesign: EBR Instructions

Pollutants in the Pond Example

Problem with Criteria & Constraints
- Explain the client's problem that needs a solution and why it is important to solve.
- List criteria and constraints you will use to decide if your solution is working.

Problem: **Runoff pollution is entering the nearby pond.**
Criteria: **The design must reduce the amount of nitrate and phosphate entering the pond and be environmentally friendly.**
Constraints: **The design must not exceed the client's budget of $65,000.**

Simplifying Assumptions
- List things that might be important but you have decided not to worry about.

We will assume that the runoff flows downhill in a straight line, unless we add a diverting duct in the design.

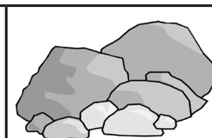
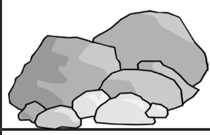
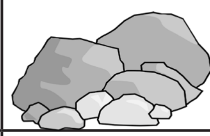
Description of Design Idea • Provide a description of your design idea.	Data/Evidence • List science/mathematics learned and/or results of tests that support your design idea.
• **Drawings of the design (which is done on sheet 5.a.)** • **Labels or pictures of structures in design (show where they are used)** • **Description of the design** • **Why decisions were made** • **Interesting features**	• **We were able to meet our goal to reduce nitrate, but not phosphate. We need to build more abiotic solutions to reduce the phosphate.** • **Our first design cost $58,000. We will used the additional money to construct a retaining pond.**

Justification - Why do you think this design idea will work?
- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

In our redesign, we will place biotic solutions closer to the pond and place a retaining garden nearby the turtle nesting grounds. This will provide homes and food for more small animals and insects. This will result in positive effects for the whole food chain and will help the ecosystem to recover. Additionally, our solution will focus on reducing phosphates above the proximity line, further away from the pond.

Name________________________________ Date____________ Period _____

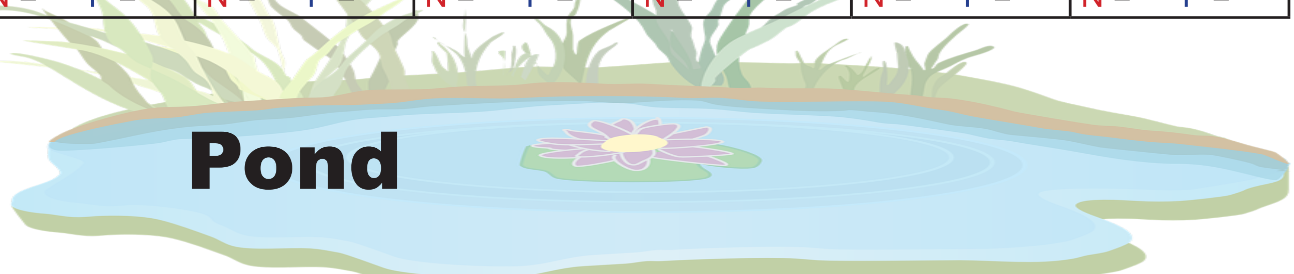
5.e. Redesign Grid Map

50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P	50 lbs. N 20 lbs. P
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =
					
N = P =	N = P =	N = P =	N = P =	N = P =	N = P =

Total:
300 lbs. N
120 lbs. P

water flow

Goal:
≤ 100 lbs. N
≤ 40 lbs. P



LESSON 5

Name______________________________ Date____________ Period _____

5.f. Redesign Data

Total nitrate and phosphate:

Fill in the amount of nitrate and phosphate that entered the pond from each column.

	column						
	1	2	3	4	5	6	total
nitrate							
phosphate							

Environmental impact:

structure	impact	amount used above the proximity line	amount used below the proximity line (multiply impact by 2)	total impact
retaining garden	+			
tree buffer zone	+++			
diverting duct	-			
retaining barrier	----			
retaining pool	--			

Environmental score:

______________ - ______________ = ______________________

(total +) (total -) environmental score

Material costs:

structure	amount used	price per unit	cost
retaining garden		$4,000	
tree buffer zone		$9,000	
diverting duct		$2,000	
retaining barrier		$10,000	
retaining pool		$6,000	
		total cost:	

LESSON 5

Name______________________________ Date____________ Period ______

5.g. Redesign Rubric

Criteria/Constraints	Exceeds Criteria/ Constraints	Meets Criteria/ Constraints	Needs Work
Amount of Nitrate	≤ 80 lbs.	≤ 100 lbs.	> 100 lbs.
Amount of Phosphate	≤ 30 lbs.	≤ 40 lbs.	> 40 lbs.
Cost	< $55,000	≤ $60,000	> $60,000
Environmental Score	≥ 10 points	≥ 5 points	< 5 points

LESSON 5

Name______________________________ Date____________ Period ______

5.g. Redesign Rubric

Criteria/Constraints	Exceeds Criteria/ Constraints	Meets Criteria/ Constraints	Needs Work
Amount of Nitrate	≤ 80 lbs.	≤ 100 lbs.	> 100 lbs.
Amount of Phosphate	≤ 30 lbs.	≤ 40 lbs.	> 40 lbs.
Cost	< $55,000	≤ $60,000	> $60,000
Environmental Score	≥ 10 points	≥ 5 points	< 5 points

EngrTEAMS © 2017 University of Minnesota & Purdue University Research Foundation Pollutants in the Pond FT 113

5.h. Teacher Observation Protocol: Redesign

Team #	All team members are on-task to retest their solution.	One or more team members are not on-task.	Team has attempted to improve the performance of their solution.	Unclear what has been done to improve their solution.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. Can you tell me about how you are working to improve your solution?
2. What were some of the other solution improvement ideas you generated?
3. How did you decide to move forward with this idea? What evidence do you have that your improved design will solve the problem for the client?

LESSON 6

Communicating with the Client

Lesson Objectives

Students will be able to:

- collaborate and discuss their findings within their teams to report back to the client.
- connect the outcomes of their testing to the impact on the environment.
- communicate their solution to the client in the form of a poster and presentation.
- justify why their design solution is appropriate based on science and mathematics.
- justify why their design solution is appropriate based on their problem scoping.
- apply evidence gathered from testing to choose solution.

Time Required

One-two 50-minute class periods

Materials

Per classroom:

- chart paper

Per team:

- poster paper
- markers

Per student:

- 1 pen
- 1 engineering notebook
- 1 EDP slider & paper clip

Standards Addressed

Next Generation Science Standards: 3-5-ETS1-B

Key Terms

memo, environmental impact

Lesson Summary

In the final lesson, students present their final design recommendation to the client in the form of a poster and oral presentation to the class. In the presentation, students use evidence to justify how their design met the client's criteria and constraints and connect their results to the larger picture, specifically how their design will impact the pond ecosystem.

Background

Teacher Background

An important part of engineering is collaboration and communication. By discussing their designs after creating *Evidence-Based Reasoning* graphics, students will practice making claims supported by evidence.

Before the Activity

Print and make copies of the following worksheets in the labeled amounts:

- *6.a. Rubric for Presentation to the Client* (1 per team)
- *6.b. Reflect About Engineering Design* (1 per student)

If you are not using duplication masters, write the engineering notebook prompts from the *6.b. Reflect About Engineering Design* on the dry-erase board or chart paper.

Classroom Instruction

Introduction

1. **Connect to the previous lesson.** Have students discuss and reflect on their first and second designs in their teams. Have them discuss the following prompts: *"How does your design match the client's needs? What did not work well and what can be improved?"* After the team discussion, students will record their responses in their engineering notebooks.

Activity

2. **Identify where they are in the engineering design process. (Communication) Ask:** *Where are we in the engineering design process today?*

3. **Prepare a presentation for the client. Say:** *Now that you have evaluated multiple designs that might be used to solve the problem, you need to present your final recommendations to the client.* Explain to the students that each team will have a maximum of 3 minutes to present their final recommendations to the client. They will also need to prepare a poster to help them present their findings. Provide students with poster paper and markers.

4. **Review the requirements.** Explain to student that they will be presenting the design that they feel best meets the client's needs. Remind students that they need to address the areas that are important to the client (criteria & constraints), which include: cost, effectiveness in reducing the amount of phosphate and nitrate in the "pond", diagrams/drawings, list of items used and impact on the environment. It should also be persuasive, neat, and organized.

Communicating with the Client

5. **Introduce the rubric.** Provide teams with a copy of the *6.a. Rubric for Presentation to the Client* to help them assess their presentation.

6. **Present the posters to the class.** Have each team present the design that they feel best meets the client's needs. **Say:** *Each team will be given 3 minutes to present their recommendations to the client.*

7. **(Optional) Write a memo to the client.** Have students practice their written communication skills by transforming their presentation into a persuasive letter, to convince the client to choose their design. Use the *6.a. Rubric for Presentation to the Client* to assess their letters, adjusting for a letter format.

Closure

8. **Reflect on engineering.** Give the students 15 to 20 minutes to individually work on the *6.b. Reflect About Engineering Design* in their engineering notebooks. After they have completed the questions on their own, have the students share their responses to the prompts in their teams. Have them discuss, develop a team response together, and complete the rest of *6.b. Reflect About Engineering Design.* You may post these sheets or make copies and have students attach them in their notebooks.

Assessments

Pre-Activity Assessment
Listen to student discussions and responses to the prompt, *"How does your design match the client's needs? What did not work well and what can be improved?"* Pay particular attention to how students address how their barrier matched their client's needs and how their barrier can be further improved.

Activity Embedded Assessment
Using the *6.a. Rubric for Presentation to the Client*, evaluate students' presentation to the client. Check to see how well they address the items listed in the rubric.

Post-Activity Assessment
Monitor student progress as they work on *6.b. Reflect About Engineering Design,* both individually and as a team. Assess their responses with the *6.c. Reflect About Engineering Design Rubric*

DUPLICATION MASTERS

- 6.a. Rubric for Presentation to Client
- 6.b. Reflect About Engineering Design

EDUCATOR RESOURCES

- 6.c. Reflect About Engineering Design Rubric

Name________________________________ Date____________ Period _____

6.a. Rubric for Presentation to Client

Criteria	2 - Great	1 - Good	0 - Missing/Poor
Cost	Provides justification of material costs.	Includes material costs, but provides poor/no justification.	Fails to include costs in their presentation.
Description of the design	Includes labeled drawing/sketches that are detailed. Provides justification for materials used.	Includes a drawing, but does not include other important information (missing labels, justifications, lack of detail).	Does not include a drawing and is missing 2 or more pieces of information.
Effectiveness of the design	Clear explanation of how well their design reduces the amount of nitrates and phosphates. Supports their explanation with multiple pieces of evidence.	Explanation of how well their design reduces the amount of nitrates and phosphates. Supports their claims with some evidence or justification.	Lacks an explanation of how well their design reduces the amount of phosphates and nitrates.
Impact on the environment	Students connect the results of their barrier to how it affects the ecosystem in extended detail and justify how their barrier will affect the local environment.	Students connect the results of their barrier to how it affects the ecosystem in extended detail, but do not justify how their barrier will affect the local environment.	Students do not explain how their barrier affects the environment.
Poster design	Poster is clear, creative, neat and organized. It is easy to read.	Poster is somewhat clear, may have some issues with readability.	Poster is disorganized and illegible.
Participation & teamwork	All team members are actively involved in creation and delivery of the presentation as a team.	All team members are involved in either the creation or delivery of the poster presentation.	Some team members are not involved in both the creation and delivery of the poster presentation.

LESSON 6

Name________________________________ Date__________ Period _____

6.b. Reflect About Engineering Design

Directions: First, **on your own**, answer each of the following questions beside the “My response” space. Then, in your teams, share your response, listen to your teammates’ responses, and discuss. Last, in the space next to “Team response”, **write your revised answer to the question**, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. **How has your <u>understanding of the problem</u> changed during the design process?**
   - Look back to the places where you defined the problem in your Engineering Notebook.
   - Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.

   My response:

   Team response:

2. **How has your <u>understanding of how to design a solution</u> changed during the design process?**
   - Look back in your Engineering Notebook to see how you developed your solution throughout solving the problem.
   - Think about what you did and how you made decisions to solve the problem.

   My response:

   Team response:

LESSON 6

Student Name______________________________ Date___________ Period _____

6.c. Reflect About Engineering Design Rubric

Problem	Question	Learning Objectives	Rubric	
6.b.1	How has your understanding of the problem changed during the design process? • Look back to the places where you defined the problem in your engineering notebook. • Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.	Communicate how their understanding of the problem deepened through the design process.	yes no	**Explained how their understanding of the problem has changed**
			yes no	**Included at least 1 of client needs, criteria/ constraints, and science/mathematics in their explanation**
6.b.2	How has your understanding of how to design a solution changed during the design process? • Look back in your engineering notebook to see how you developed your solution throughout solving the problem. • Think about what you did and how you made decisions to solve the problem.	Communicate how their understanding of how to design solutions changed through the design process.	yes no	**Explained how their understanding of the how to design a solution has changed**
			yes no	**Included at least 1 example from their experience or how they made decisions in their explanation**

Notes:

Notebook Prompts and Titles

Teacher Directions:

If you prefer to have students write the answers to prompts right in their notebooks (rather than on the handouts and then adhere them to the notebooks), you should have the students put the bold title for each prompt and then answer the question that follows. The format for each will be as follows:

> **Prompt title:**
> Question to answer

Have students answer each set of questions as they appear in the curriculum. If any questions are included in the curriculum, but not included here, you may determine the title for the prompt.

Problem Scoping Lessons - Define and Learn

Section 1:

Engineers:
What do engineers do?
Solve Problems:
How do engineers solve problems?

Section 2:

Questions for client:
What are at least 3 questions that you want to ask the client that will help you understand the problem better? Make sure to ask about all important aspects of the problem.

Section 3:

Client:
Who is the client?

Problem:

What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.

End-users:
Who are the end-users?

Criteria:
What will make the solution effective (criteria)? Use detailed information you have from the client.

Constraints:
What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.

What we need to learn:
Think about the problem of the runoff pollution from nearby farms. In terms of cost, how to prevent runoff, and impact on the surrounding ecosystem, what are at least 2 things you need to learn in order to design an effective solution? Make sure to consider all important aspects of the problem. Be specific.

Notebook Prompts and Titles

Generate Ideas/Plan Lessons

Section 1:

EBR Graphics can just be drawn in notebooks.

Section 2:

Have students answer the following after EBR graphics are complete.

Pros and Cons:
What are the pros and cons of each of your own solution ideas?

Why we chose our solution:
Which solution did your team choose and why? Provide evidence for your reason.

Test Solution Idea(s) Lessons

Section 1:

Ask students to complete after they have run their tests.

Test results:
What were the results of your test(s)?

Learned from test results:
What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work.

Changes from test results:
What changes will you make to your solution based on the results of your tests?

Reason for changes:
Why will you make those changes? Think about the results of your test and the science and mathematics you have learned.

Section 2:

Section 2 questions should come after the students have run their tests and have had an opportunity to answer Section 1 questions.

How solution meets criteria and constraints:
In what ways does your solution meet the criteria and constraints of the problem?

How solution does not yet meet criteria and constraints:
In what ways does your solution not yet meet the criteria and constraints of the problem?

Notebook Prompts and Titles

Redesign Lessons

Ask students to complete after they have run their redesign tests.

Test results:
What were the results of your test(s)?

Improvement?:
Did your redesign improve your solution? Why or why not?

Next ideas for improvement:
If you could do another redesign, how would you try to improve your solution?

Final Solution Lessons

Section 1:

Students use evidence-based reasoning in reporting their final solution to the client. This can happen through use of the EBR graphic as part of their memo or presentation, or you can have the students include the aspects of the EBR graphic (without the graphic itself) in the memo or the presentation.

Section 2:

These questions should be completed after presenting the solution to the client and the entire design challenge is complete.

Understanding of the problem:
How has your understanding of the problem changed during the design process?

- Look back to the places where you defined the problem in your engineering notebook.
- Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.

Understanding of designing a solution:
How has your understanding of how to design a solution changed during the design process?

- Look back in your engineering notebook to see how you developed your solution throughout solving the problem.
- Think about what you did and how you made decisions to solve the problem.

Generate Ideas/Plan Lessons