EcoMUVE Pond Teacher Guide

DRAFT ONLY

4.12.12

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This work is supported by the Institute of Education Sciences, U.S. Department of Education, Grant No. R305A080514 to Chris Dede and Tina Grotzer. All opinions, findings, conclusions or recommendations expressed here are those of the authors and do not necessarily reflect the views of the Institute for Education Sciences.

Overview

What is EcoMUVE Pond?

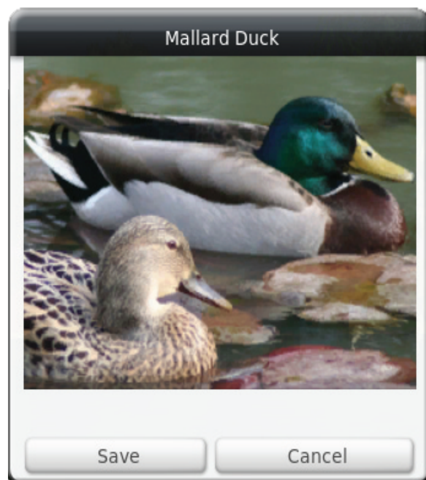
Dear Teachers,

This EcoMUVE engages your students in a pond ecosystem investigation. As "scientists", students will monitor and make recommendations to the town on environmental and water quality issues.

As students work, they learn *fundamental ecosystems concepts* as well as important *causal patterns* that will help them learn to deal with complexity in their world. Their work is motivated by a problem in which many of the fish that live in the pond have died. Students use their understanding of ecosystems concepts and causal relationships to present their ideas about what caused the fish to die.

Inquiry and Measurement

The exploratory nature of the EcoMUVE leads to *inquiry-based learning* that mimics authentic inquiry-based learning in the real world. However, because it is possible to add scaffolds for students to assist them in their reasoning, it avoids many of the pitfalls of inquiry-based learning where students who are novices are trying to reason in expert ways.



Because observations in the EcoMUVE world are somewhat limited to the available measurement tools and dialogue with Non-Player Characters, students are less likely to be distracted by irrelevant observations or misunderstood prior experiences with such environments. Students therefore make precise measurements and observations before developing inferences based on the collected data.

Complex Causality

The EcoMUVE also aims to teach students the types of causal reasoning necessary to deeply understand ecosystem concepts and transfer them to new contexts. Research shows that students who understand how to reflect upon their causal default assumptions and how to think about causal patterns learn science concepts better than those who do not. Students are also better able to transfer their learning to new subjects.

The causal patterns taught in the EcoMUVE are the result of over ten years of NSF-funded research with students in middle school as part of the Understandings of Consequence Project. The patterns are also part of the curriculum series resulting from this work called“Causal Patterns in Science” including the ecosystems module entitled “Causal Patterns in Ecosystems.”

Table of Contents

The Student Process

Steps in the Student Discovery

The paragraphs that follow describe the student experience in the EcoMUVE. It is very important that you do not share these details with the class and that you instead allow the EcoMUVE to unfold through the students' investigations. This way, the students will learn not only science concepts, but also the important inquiry skills critical to scientific discovery outlined in the National Standards.

Part 1: Getting to Know the Pond Ecosystem

Students begin by visiting the pond and becoming familiar with the species living there, the surrounding environment (abiotic and biotic), and the local residents. When students first visit the pond, they are most likely to pay attention to the things that they can readily see: the fish, the frogs, the surrounding vegetation, and so forth. But soon they will find out that as ecosystem scientists, it is important that they also attend to things that they cannot see.

Using the submarine tool invites students to start to consider organisms that they cannot see: the many thousands of phytoplankton and zooplankton that play a critical role in the pond ecosystem. By zooming in on these microrganisms, they will discover a new world—so tiny that they cannot see it with their own eyes, but one that is essential to life in and around the pond.

Part 2: Measurement and Monitoring

Students will be introduced to the measurement tools for water, weather, populations, and the calendar tool so that they can make observations and collect measurements on different days of the simulation. Students will work in teams; within a team, each student has a different role and must become an expert in certain aspects of measurement and monitoring in the virtual world. Students develop their expertise by using the *Learning Quests* to gain an introduction to the major components of water quality. Once students have completed the Learning Quests, and thus achieved a working knowledge of water quality metrics, they may monitor these metrics during the course of the module.

Students will observe that after a period of relative consistency, the numbers of phytoplankton begin increasing over time. Some students will wonder why, while others will miss this clue entirely. As events unfold, this dynamic could become part of a class discussion about why steady-state monitoring is so im-

portant in understanding and managing ecosystem relationships. Eventually the students should all notice that the phytoplankton is increasing; it will become obvious as the water of the pond becomes greener and greener.
What the students are noticing is the process of *eutrophication*. Characterized by domino causality, the increase in plants leads to an increase in organisms that depend upon green plants. It also leads to increased decay as the plants die. This, in turn, leads to an increase in detrivores, such as amphipods and caddisfly larvae. Students should notice changes in water measurements that they collect. If they are very observant, they might also notice that the water is becoming a little murky and the temperature in the pond is slowly rising.

However, there is something else happening that they cannot see. The increased plant decay also leads to an increase in bacteria, which are invisible to the naked eye—a non-obvious cause. The bacteria that are eating the decomposing plants are thriving, but they are also using up the dissolved oxygen in the water.

Very soon, many of organisms that thrived because of the increase in green plants are gasping for oxygen. The most obvious of these is the fish (notice the fish are swimming close to the surface on July 25th). With lower photosynthetic production of oxygen and the use of oxygen by all of the bacteria, the fish are more desperate on cloudy days and there are more fish at the surface, particularly just before dawn.

When the students visit the pond on July 28, there are dead fish along the shore. Observant students will notice that the fish kill followed a couple of cloudy days without wind.

Part 3: Figuring Out What is Going On

If students have collected all of the data, they will see patterns that look like those in the graphs available in Appendix C. Students may notice changes in phosphates, nitrates, chlorophyll a, oxygen, turbidity, weather variables, and population sizes. These changes are related to one another and many of these changes give hints about what caused the fish kill.

In order to put the pieces of the puzzle together, students are asked to examine what variables have changed over time. In efforts to explain why these changes are happening in the pond, the students will draw on observations and information they have gathered elsewhere in the environment.

The EcoMUVE environment provides an open forum in which students can use scientific inquiry to pursue their own path of discovery. Below we provide a few potential paths by which students could uncover important parts of the fish-kill story.

As the students visit the pond on different days, most notice dramatic changes in the color of the pond. By talking to Julia Santorino, the students find out that the pond is not usually so green. Students may wonder what is causing the pond to be so green. By using the water measurement tools and the submarine, students will learn the connection between the green color and the tiny floating plants (algae) in the pond. They realize that the pond is so green because the algae population has increased.

Students may also notice that phosphates changed quite a bit over time. As students try to understand why the phosphate concentration changes over time, they may notice that the fertilizer that is being used in the watershed contains phosphate. During their first visit, they see Manny preparing to apply a fresh load of fertilizer to the lawns near the pond. After reading the information on the fertilizer bag, and gathering information from the Atom Tracker tool, students will learn that phosphates that have not been used by plants can be washed off of the ground when it rains. Students who visit the pond on July 6th will notice that there is plenty of rain falling near the pond. The Atom Tracker tool will also help students recognize the critical role that phosphate plays in supporting the growth of plant populations. Thus, students will discover that phosphates likely had something to do with why the algae population increased.

Using the population tool, or by observing organisms in the submarine, students may notice a dramatic change in the number of bacteria that are in the pond. The bacteria population increases dramatically just days before the dead fish are found. Because many students recognize that bacteria can cause diseases, some students may think that the bacteria caused the fish kill. However, when students use the Field Guide to learn more about bacteria they will find out that many bacteria that live in ponds are decomposers. Students may begin to think of the increase in bacteria as an effect rather than a cause. Students will learn more about the role of bacteria through the Atom Tracker and find out that bacteria thrive on dead plants and animals. Students will also discover that bacteria use a lot of oxygen during the process of decomposition. With this new information, the decline in oxygen on July 25th begins to make sense.

Students may also notice that not all the fish died between July 25th and July 28th. On July 28th, students can still find fathead minnows in the pond. If students use the Field Guide to learn more about fathead minnows, the students will find that these fish happen to be tolerant of high temperatures, high turbidity, and low oxygen concentrations. This may give students a clue about the variables that might have caused the other fish to die. The change in dissolved oxygen that immediately precedes the fish kill may be a strong connection that draws the students' attention. Otherwise, the Atom Tracker tool will give the students clues about the importance of dissolved oxygen for fish health.

Thus, there are multiple pathways that students may take as they discover components that contribute to the fish kill. Rich hints and clues are provided through each of the tools and non-player character interactions built into the MUVE.

Part 4: Supporting Explanations with Evidence

The final part of the EcoMUVE involves students in generating multiple possible explanations and working as a group to decide which hypothesis best explains the fish kill. The process of exploring multiple explanations challenges students to support their ideas with evidence. The group discussion will also help students construct an understanding of the pond ecosystem that incorporates the complex causal relationships highlighted above. Each group must then present their best, most-detailed explanation, along with supporting evidence, to the rest of the class.

Variations on Student Paths through the EcoMUVE

While this guide presented the typical story of how students might work through the EcoMUVE, there are other equally valid paths. Students have some basic measurement tools available throughout the MUVE and may use these to monitor the pond from the start. For instance, if students watch dissolved oxygen levels over time, they would see increased oxygen production from the plant growth during the day, especially on sunny days, but also greater decreases in oxygen from animal and plant respiration and organic matter decomposition at nighttime and during cloudy weather. In this way, movement through the MUVE honors all good ecosystems thinking.

The Jigsaw Process

The jigsaw approach to activities involves assigning specific roles or areas of expertise to individual students in a group who work independently on their section and then share their findings with the group. Together, the group must synthesize and make sense of the collective findings. In this manner, not only do students still gain exposure to all aspects of the activity through their classmates, but they also gain a much deeper understanding of their area of expertise than they would have by reviewing all of the material quickly.

Translating this technique into the EcoMUVE involves placing students in small groups and assigning them to one of four roles: *Water Chemist, Microscopic Specialist, Naturalist and Private Investigator.*

Both methods of experiencing the MUVE (independently or in a jigsaw configuration) offer benefits to the learning process, and their use is up to the discretion of the teacher. If there is sufficient class time allotted to the MUVE, or if a teacher has particularly advanced students, independent work will offer students an experience in a rich, thorough inquiry process. Conversely, limited time allotted to the software might merit the use of the jigsaw. The jigsaw is also encouraged in cases of classroom differentiation, where a teacher can assign higher- level students to roles that offer more challenges.

Final Presentations

The final class activity involves students making a presentation. In this presentation, students put forth their conclusions about what is happening to the pond and their evidence to support their conclusions. This presentation offers an excellent opportunity for you to assess their understanding of the science, their reasoning about evidence, and their presentation of scientific ideas.

Background

Concepts and Content

Black's Nook and Scheele Pond

"Scheele Pond" in EcoMUVE is modeled on a real freshwater pond in Cambridge, Massachusetts, called Black's Nook. Black's Nook is located in an urban setting next to a golf course and a busy road. It is also close to Fresh Pond, which provides drinking water to the city of Cambridge as part of the Cambridge Reservoir System. Black's Nook and other small ponds were formed artificially after gravel dikes were built in Fresh Pond during the last century to support road construction.

Cambridge is located in a humid continental climate zone, where the winters are cold enough to maintain snow, but warm seasons can sustain substantial plant growth. Patches of deciduous forest surround Black's Nook, but the populations within are limited and altered by the urban developments nearby.

Although the focus of this EcoMUVE is on the pond itself, the pond's ecosystem is not limited to aquatic organisms. Terrestrial organisms (birds, mammals, trees) as well as abiotic factors (inputs to the carbon, nitrogen, oxygen, and water cycles) from the area cause changes in the pond. Black's Nook hosts creatures ranging in size and phyla from the great blue heron all the way down to microscopic plankton and bacteria suspended in the water and sediment. Complex interactions occur between plants, animals, and abiotic inputs.

Watersheds

The water conditions within Black's Nook are part of an open system. The low depression in which the nook was formed acts as a drainage basin for the surrounding area. Due to gravity, bodies of water at the lowest points of these land areas act as a depository for chemicals and small objects that can be carried by runoff. This washing of chemicals from streets, lawns, and homes presents the greatest human input to aquatic ecosystems, rather than fishing (as many students may assume).

Abiotic Factors

In order to solve the larger puzzle of this EcoMUVE module, students must first develop a clear understanding of a number of abiotic factors and their influence on the aquatic system. There are many abiotic factors:

- **Dissolved Oxygen**
    - Aquatic organisms require oxygen to undergo respiration, and their survival is contingent on enough oxygen molecules being dissolved in the water. This oxygen is filtered from the water through the use of gills or is transported directly through cell membranes.

    - Dissolved oxygen (DO) levels are raised by physical turbulence and photosynthetic rates (and therefore sun exposure). Additionally, colder water has a higher saturation level for dissolved oxygen, and tends to have higher concentrations of dissolved oxygen. Dissolved oxygen concentrations are measured in the number of milligrams of oxygen per liter of water (mg/L). Normal range for dissolved oxygen measurements are between 6 and 10 mg/L. If DO concentrations are below 6 mg/L, it can cause stress for aquatic organisms. Concentrations of DO lower than 2 mg/L over an extended period of time can be lethal to fish and some other aquatic life (e.g. mayfly larvae, aquatic snails).

    - Insufficient dissolved oxygen concentrations are the direct cause of the fish kill.

- **Nitrates and Phosphates**
    - Nitrates and Phosphates are specialized molecules of nitrogen and phosphorous that cause increased growth in any type of plant. They therefore play a crucial role in aquatic systems and are frequently utilized by humans in the manufacture of fertilizers and other chemical products.

    - An increase in either chemical can lead to a boom in plant populations, including rooted plants and algae.

- **Chlorophyll A**
    - Chlorophyll a is a chemical compound that allows plants to use the sunlight they absorb. It also gives plants their green color. Scientists measure the concentration of chlorophyll a in the water sample to gather population information about algae in the water.

- **pH**
    - pH is a measure of how acidic or basic the water is. There are many things in nature that can affect the pH of the water, including the amount of CO_2 in the water. Typical pH readings are between 6 and 8.

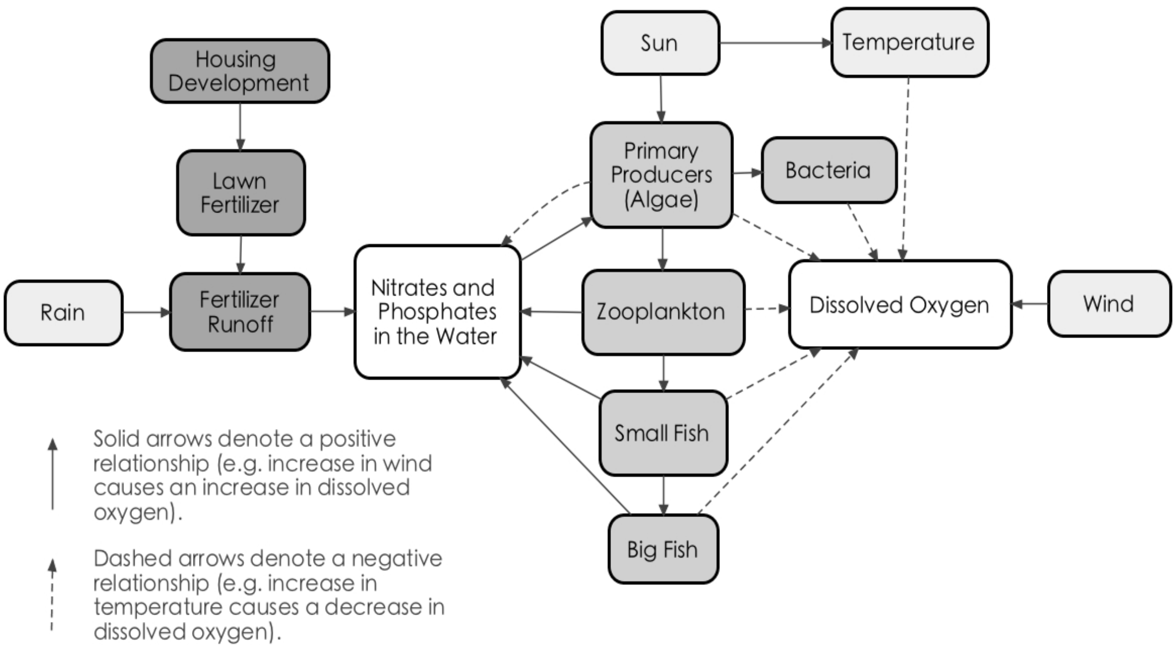
- **Turbidity**
    - Turbidity is a measure of how cloudy the water is. Turbidity is affected

by dirt mixed into the water or by floating microscopic plants. Readings between 0 – 30 NTU are typical.

Complex Causality

Ecosystem complexity is a result of numerous inputs, members, and interactions that exist in ecosystems. Changes in organism populations or resources are not independent events; a change in the population of one species affects the many other species that are present.

Within the EcoMUVE modules, there are focal causal patterns and features that students will encounter.



This diagram highlights the relationships that are a part of the EcoMUVE and are represented in Scheele Pond. Components of the ecosystem, both biotic and abiotic, are represented by boxes. An arrow connecting two boxes indicates that those two components are related and the arrow indicates the direction of the relationship. For example, the amount of sunlight affects the temperature. Students will be asked to develop a concept map of the relationships that they discover in Scheele Pond. Their concept maps will likely not have this many pieces and connections, but the teacher may use this concept map as a guide for the kinds of relationships students should be noticing in the pond. There are several common types of relationships that may be found:

- **Linear Causal Pattern**
    - One organism or environmental variable affects another. This is the

simplest example of an ecological relationship that is often the easiest for students to comprehend, and the one they will most often assume is present.

- **Domino Causal Pattern**
  - A series of linear relationships affect one another in sequence, which often makes the initial cause difficult to discern. Such complex relationships are common in food webs, and domino causal patterns may emerge when a population of an organism in a food web changes dramatically.

- **Cyclic Causal Pattern**
  - A cause precipitates an effect that, in turn, has an effect on the initial cause. For instance, plants grow and then die in ecosystems. Decomposers release nutrients within the plant back into the soil affecting the growth of other plants.

- **Two-way Causal Pattern**
  - One event or relationship has mutual, and often simultaneous, effects. Each component has an effect on the other, so each acts as both an effect and a cause.

- **Reasoning about Balance and Flux**
  - Ecosystems involve both balance and flux. Many scientists refer to this as a dynamic stability. There is a great deal of redundancy and ability to adapt in ecosystems that provides balance. However, ecosystems typically include some fluctuations as well. Flux is not necessarily negative: it can create patterns in an ecosystem that are ultimately healthy. For instance, it can allow for new species to become established. Students typically reason that flux or change is bad. This can make it difficult to detect the role of flux in positive outcomes.

- **Non-obvious Causes**
  - When causes are not obvious, it can make it harder to see causal patterns. An example of a non-obvious cause is represented by the role of bacteria in decomposition.

- **Changes Over Time**
  - We tend to readily notice "event-based causality". The students witness an "event" – the fish kill – yet they will find that the death of the fish was caused by a series of events that unfold over time. It is important to monitor changes over time to fully understand the cause of the event. It is important to monitor changes over time to fully understand the patterns that emerge.

- **Spatial Gaps, Scale and System Boundaries**
    - We tend to look for spatially local effects, but changes in ecosystems may be caused by changes far away. It is important to question where we draw the boundaries when thinking about ecosystems relationships.

Fish Kill

During the process of the EcoMUVE, the large fish in the pond die overnight – an event known as a fish kill. While most students assume there is an isolated cause, such as poisoning, fish kills are the result of a series of events and changes described below.

Runoff carries excess fertilizer and other waste chemicals to water sources where these chemicals can build to extremely high levels. The phosphorus and nitrogen in the fertilizer support growth of aquatic plants, and their subsequent build-up in the body of water causes an algal bloom, or an increase in the biomass of microscopic aquatic producers. The population size of the algae had previously been limited because there were not enough phosphates in the pond.

For a short time, eutrophication occurs in the body of water due to the input of phosphates from the fertilizer. This productivity is brought to an abrupt end when levels of phosphate become too low to support further growth of the algae population (phosphate, once again, is a limiting factor). These dead algae accumulate on the bottom of the pond.

Bacteria, which are the dominant decomposers in aquatic ecosystems, consume the dead algae. During the process of decomposition, the bacteria use up a lot of the oxygen in the pond. On July 25th, there was not enough oxygen produced during photosynthesis during the day to support the amount of oxygen that would be used during respiration at night. The problem is exacerbated by the fact that the weather is warm, cloudy, and without wind. These contribute to low oxygen conditions in the pond. Therefore, dissolved oxygen concentrations in the pond get very low overnight. This, in turn, leads to the death of aquatic organisms that were reliant upon the dissolved oxygen to live.

Further details as to the exact clues available to students in the EcoMUVE are explained in the appendices. Student learning of ecosystem concepts and causal relationships is driven by their struggle to understand the complex causes of the fish kill. It is a difficult conclusion to reach independently; therefore, the lessons section of the guide contains ways for the students' teacher and peers to support them as they explore the ecosystem in the virtual world.

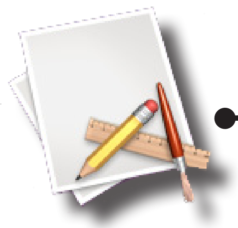
Software Quick-Start Guide

Getting Set Up with the MUVE

Launch and Configuration

Get started in no time!

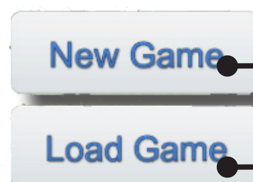
1



EcoMUVE
Pond

Double-click on the EcoMUVE Pond icon to open the program.

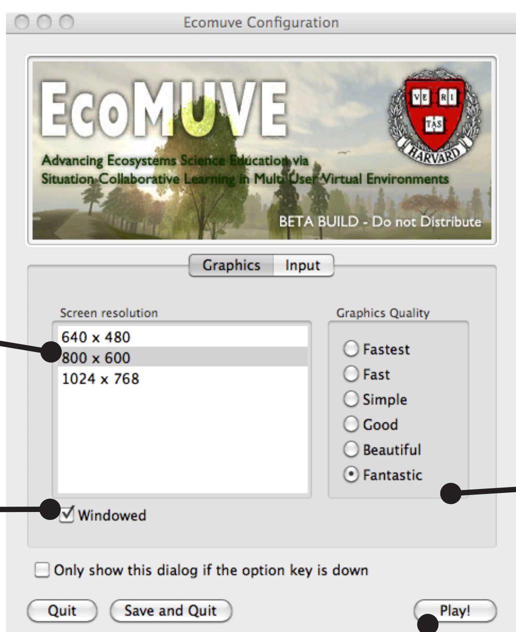
3



Click here to start a **new game**.

Click here to open a **saved game**.

2



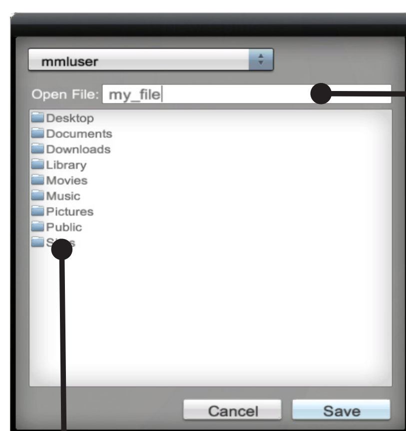
Select your preferred **screen resolution** here.

Selecting **windowed** allows you to view the screen as a separate window.

Select the **graphics quality** here.

Click play to start!

4



Type your **file name** here.

Select your **saved file** here.

A note about file management:

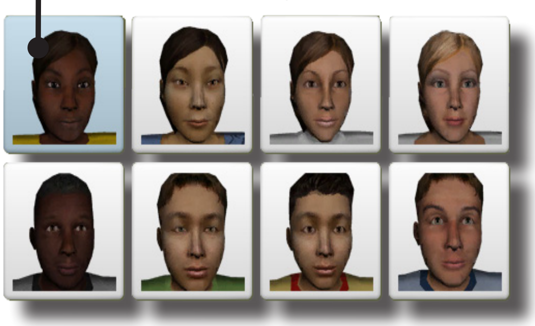
Students will be using the EcoMUVE software over the course of several days, and will want to be able to return to their saved games. To do so, they will need to have access to their individual game file. When thinking about how you will use EcoMUVE in your classroom, you will want to consider the following:

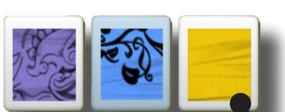
- How will students *name* their files for easy identification?
- Will students use the *same computer* (each time they log on)?
- If students use different computers each time, how will they *save and transfer their files* (from one computer to another)?
- How will students transfer their files from one computer to another to share their data files?
- How will you *share the master data file* (available for download from the EcoMUVE website) with students if necessary?

Settings

Create your avatar and set your preferences.

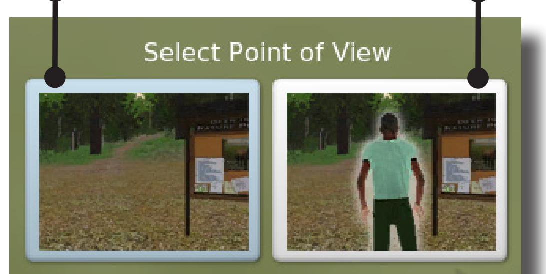
Select the gender and skin color of your avatar by clicking on one of these.





Select the shirt color for your avatar by clicking on one of these.

Select first-person or third-person view.

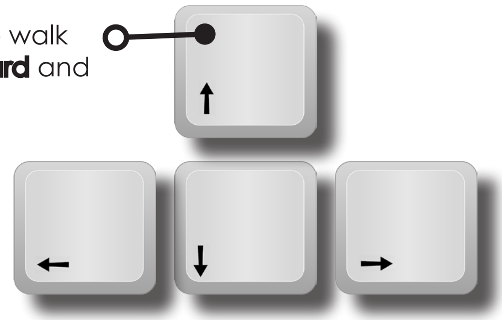


Select the **settings** button to get to these options.

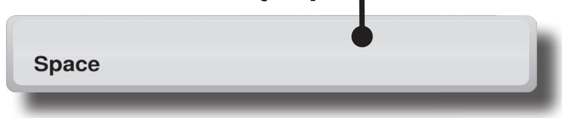
Navigating

Explore the environment by walking around.

Use the arrow keys to walk **forward and backward** and turn left and right.



Hit the spacebar to **jump**.



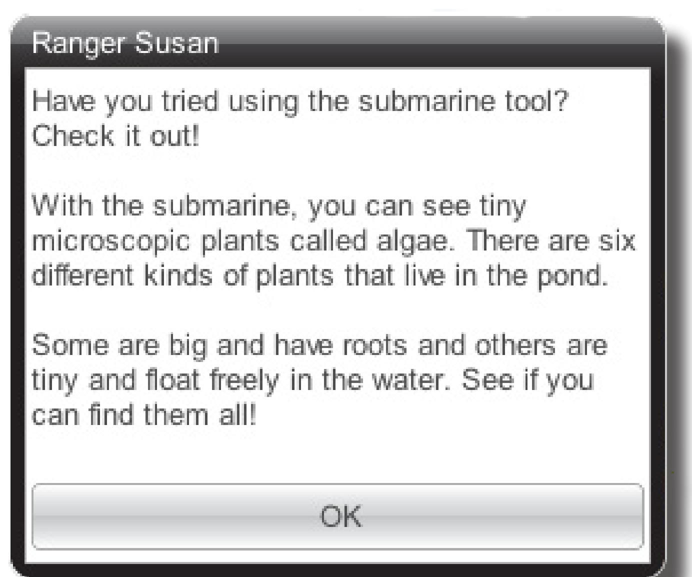
If you are using a PC, right click and move the mouse to **look up and a down**.

If you are using a Mac, hold down the option button and move the mouse to **look up and down**.

Characters

Various characters will be present on different days to provide clues.

Click on a character to see what s/he has to say.

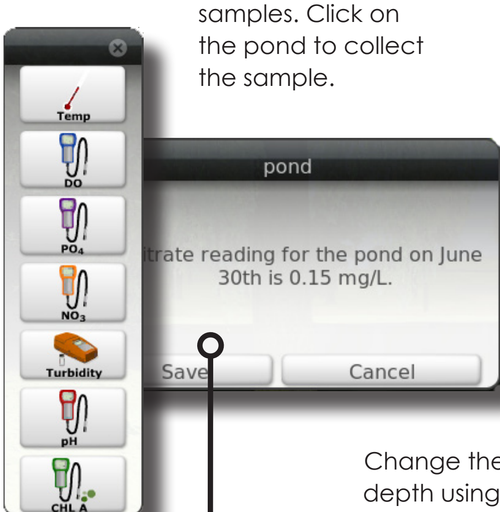


The Toolbar

All the tools you need are located in the toolbar at the bottom of the screen.

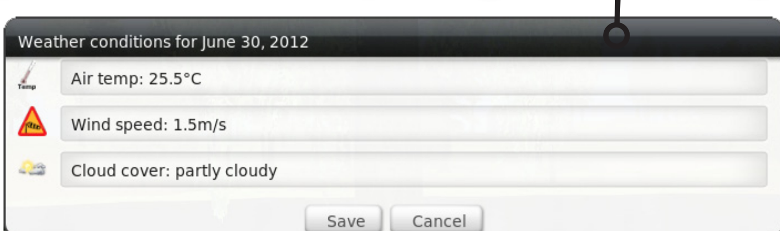
The **submarine** tool allows you to see the microscopic organisms living in the pond. Select a place to dive, then navigate using the arrow keys. To return land, select return to shore.

The **water measurement** tool opens a toolbar that allows you to collect water samples. Click on the pond to collect the sample.



Change the depth using the arrow keys or the depth control.

Change the magnification using the magnification buttons.



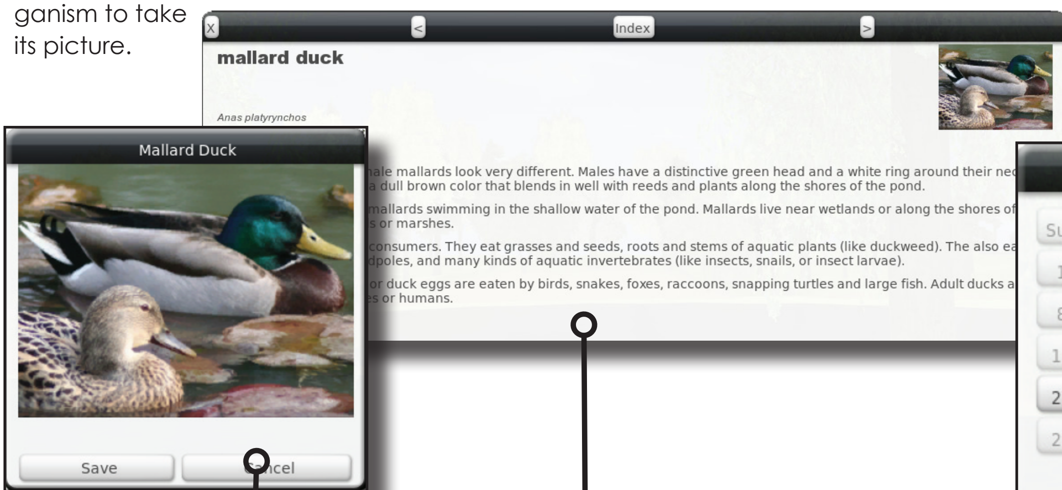
The **population** data tool allows you to collect population data about various species. Click on an organism to collect population data for its species.

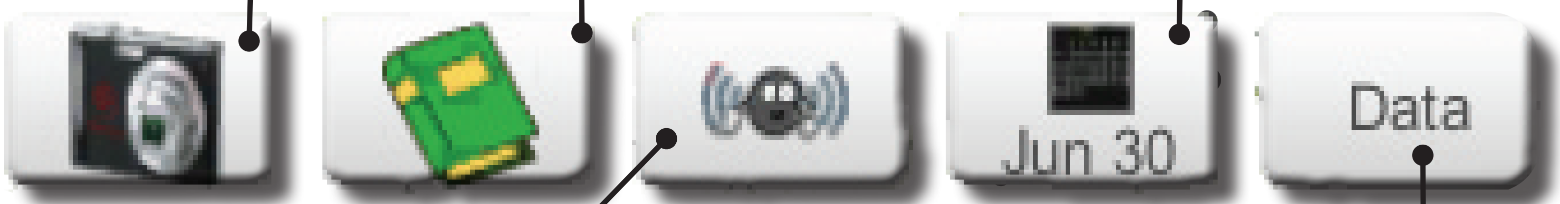
The **weather measurement** tool provides information about the weather.

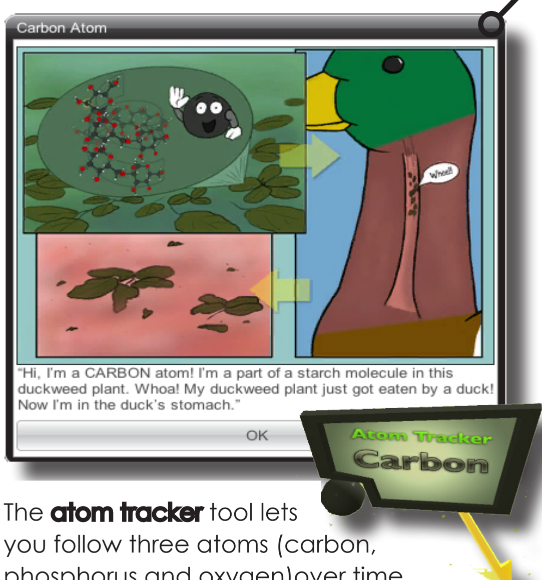
The **camera** takes pictures of organisms. Click on an organism to take its picture.

The **field guide** displays information and images of the plants and animals. Select the name of an organism to read more about it.

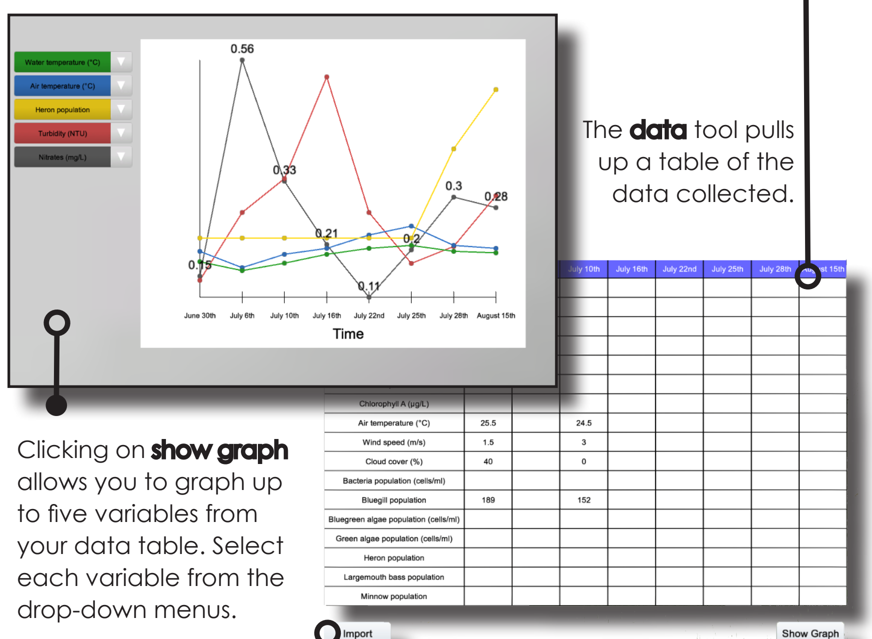
The **calendar** lets you travel through time to different days. Click on the calendar tool to open the calendar, then select one of the highlighted days in June, July and August.







The **atom tracker** tool lets you follow three atoms (carbon, phosphorus and oxygen)over time. Signs visible in the world describe what happened to atoms since the last time you saw it.



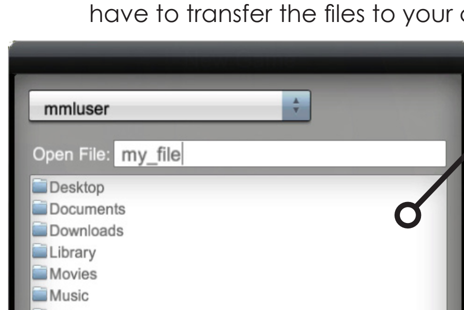
The **data** tool pulls up a table of the data collected.

Clicking on **show graph** allows you to graph up to five variables from your data table. Select each variable from the drop-down menus.

Select this **import** button to upload data files from other users. To access files from other users, you will have to transfer the files to your computer.

Sharing Data

Upload data from other users.



The Lessons

Overview of the Curriculum

This section includes the lesson plans for each of the eleven lessons in the Eco-MUVE Pond unit.

Lesson Structure

The lesson plans are structured around four key areas of instruction:

1. *Analyze:* Access prior knowledge, interest, and inquiry
2. *Expand:* Introduce new content
3. *Explore:* Initiate self-directed discovery
4. *Review, Extend, Apply:* Reconnect to content, personal connections, and opportunities to use elsewhere

This structure is adapted from the format used by Understanding of Consequences curriculum developed by Tina Grotzer at Project Zero.

Lesson Summaries

Lesson 1: Students are introduced to a pond ecosystem and get acquainted with the EcoMUVE virtual world environment. They get a chance to explore the world and look for organisms in the pond ecosystem.

Lesson 2: Students learn the roles of producers, consumers, and decomposers within an ecosystem and how to categorize organisms accordingly. Additionally, students arrange organisms in a food web that represents the transfer of energy from one organism to another in an ecosystem.

Lesson 3: Students learn about biotic and abiotic factors and use the Learning Quests to learn how to take water measurements. They discover the fish kill on July 28.

Lesson 4: Students are grouped into teams of four and each member takes on a unique scientific role to help their team determine what may have caused the fish to die. They explore the pond ecosystem through the eyes of their scientific role, and use their role sheets to find important information.

Lesson 5: Students learn what an atom is and understand its role in an ecosystem by completing the atom tracker worksheets and answering the atom tracker questions.

Lesson 6: Students learn how what they learned about atoms relates to ecological processes like photosynthesis, respiration, and decomposition. They get into their teams and look at trends in the data and, as a class, discuss how the atom tracker experience may help explain some of those trends.

Lesson 7: Students learn how to represent complex relationships using a concept map with a real-life example. With their team, they construct a concept map of what caused the fish to die in EcoMUVE.

Lesson 8: Students use the tables and graphs in EcoMUVE to find evidence that supports their theories of the causal relationships represented in the concept maps they developed about what caused the fish to die.

Lesson 9: Students get into their groups and agree on a final hypothesis for what caused the fish to die, compile the evidence to support their hypothesis, and revise concept maps accordingly.

Lesson 10: Student groups present their findings to the class. Classmates are encouraged to pay attention during the presentations to listen for what evidence the presenters are providing and to ask questions.

Lesson 11: Students groups finish presenting. Students are asked to reflect on and share how participating in this EcoMUVE investigation makes them think differently about cause and effect in the real world, and how causality ties in with other science lessons they have learned.

Making Discoveries in the Ecosystem

Lesson 1

Summary
Lesson 1 is designed to introduce a pond ecosystem and get students acquainted with the EcoMUVE. They will explore the world and look for organisms in the pond ecosystem.

Understanding and Performance Goals
- Students will get to the know the ecosystem, learn how to navigate in the world, and use the camera, submarine, and field guide to explore the new world.

Time
- 40 min. (30 min. at the computer)

Materials
- Flipcharts, whiteboard, chalkboard, or projector
- Computers, ideally one per student

Advanced Preparation
1. Ensure that computers are ready for students to use.
    - Install EcoMUVE on all computers.
    - Have a plan for where students will save their files.

Analyze (5 min.)

1. Ask students to describe what an ecosystem is:
    - What types of types of things might we expect to find in a pond ecosystem? (Plants and animals, biotic and abiotic, or living and non-living things)

2. Encourage them to pay attention to the kinds of organisms they see and note whether they find any abiotic parts of the ecosystem.

Expand (10 min.)

1. Have students move to the computers. Alternatively, you may want to demonstrate these aspects of the virtual world to the students using the projector before allowing students to work on their own computer.

2. Have them practice navigating using the arrow keys. Explain that there is an end to the world, so they may have to turn around and go the other way. The space bar may help them hop over things if they get stuck.

3. Have students find the camera tool and practice taking pictures.

4. Then have students find the submarine tool and go underwater. Have them use the zoom tool to look at small organisms in the pond at different levels of magnification. Have students take pictures.

5. Show students that when they save pictures, they are taken to the field guide. Explain that they will be using this field guide to learn more about the species living in the pond ecosystem.

6. Students may explore the other tools (Measurement, Weather, Population, and Calendar tools) as well, but these are not the focus of this lesson. Answer any questions that come up, but remind students that they will learn more about these tools in Lesson 3.

Explore (20 min.)

1. Explain that the goal for today is to see how many different organisms they can find and that at the end of the day, the students will be asked to share with the class some of the organisms they found.

2. Circulate around the room to help students explore the Scheele Pond and get used to using the tools.

Review, Extend, Apply (5 min.)

1. Go around the room and ask each student to name one organism they found, or to share how many organisms they found.

2. Ask students to share whether there were any questions that came up. Ask for a few students to share some of the interesting experiences they had in EcoMUVE.

3. Make a note of any questions that students bring up.

Food Webs and Energy Transfer

Lesson 2

Summary

Students will learn the roles of producers, consumers, and decomposers within an ecosystem, and will be able to categorize organisms accordingly. Additionally, students will be able to arrange organisms in a food web that represents the transfer of energy.

Understanding and Performance Goals

- Students will understand the role of producers, consumers and decomposers in an ecosystem.
- Students will recognize that producer, consumer, and decomposer are useful categories for grouping organisms.
- Students will identify examples of producers, consumers and decomposers and arrange them in a food web that represents energy transfer in an ecosystem.

Time

- 40 min. (30 min. at the computer)

Materials

- Flipcharts, whiteboard, chalkboard or projector
- Computers (ideally one per student)
- Food Web Activity Worksheet

Advanced Preparation

Note: A tutorial video on the food web tool is available on the EcoMUVE website download page.

1. Label your board with producer, consumer, and decomposer.
2. Ensure that computers are ready for individual use, **with internet access.**
3. Secure access to a printer so students may print complete food webs.
4. Reproduce the Food Web Activity Worksheet.

Analyze (5 min.)

1. Have students recall organisms they found the previous day in EcoMUVE.

2. On a whiteboard or flipchart make a list of things that fit in the following categories: Producer, Consumer, and Decomposer. The list need not be exhaustive, but should serve to remind students about their experiences in EcoMUVE on the previous day.

3. Share the following definitions and have students double-check whether items are appropriately placed:
    - **Producer:** An organism that can make its own food through the process of photosynthesis.
    - **Decomposer:** An organism that eats dead organic matter. Most are bacteria and fungi.
    - **Consumer:** An organism that feeds on other organisms because it cannot make its own food.

4. Ask why each of these is important to an ecosystem.

Expand (5 min.)

1. Demonstrate how to use the food web tool to the students using the projector before allowing students to work on their own computer.
    - *Access the food web tool at* http://ecomuve.gse.harvard.edu/food-web/foodweb.html

2. Learn more about which organisms eat which using the online Pond Field Guide. There is a link to the Field Guide within the food web tool.

3. Distribute the Food Web Activity Worksheet to the students to note their findings.

4. Have students move to the computers.

Explore (20 min.)

1. Explain that the goal for today is to use what they have learned so far about the organisms to construct a food web that represents the flow of energy through the ecosystem.They do not need to use all of the organisms in their field guide, but they can try to use as many as possible in the time they have available.

Note: Students may encounter a hurdle if they draw the "connect arrow" in the wrong direction. If a student is representing the relationship between bluegill *and zooplankton, the student may draw an arrow from bluegill to zooplankton – showing that bluegill eat zooplankton. However, food webs are meant to show the direction the energy is moving, rather than what eats what. So, the arrow should point from the zooplankton to the bluegill. This hurdle provides a valuable teaching moment that can cause a student to recognize their own misconception and see the need to fix it before they are able to proceed. Spend a few moments with students who encounter this problem and help them reflect on why the arrow should point in the other direction.*

2. Circulate around the room to help students.

Review, Extend, Apply (10 min.)

1. If a printer is available, you can ask students to print their final food web. Use a projector or white board to display an example food web in front of the class. As the food webs are printing, conduct a whole class discussion around the following topics:

    - Was there anything about the food web tool or activity that surprised you? Students may mention the direction of the arrows or the fact that the food web does not work, or light up if the sun is not connected, or the decomposers are not connected.
    - Did anyone have a hard time using the connect tool at first? What did you learn?
    - What parts of the food web are absolutely critical? (sun, decomposers, producers)
    - What would happen if you removed X organism from the food web? Pick any organism and discuss the implications of removing this organism from the food web. You should discuss the idea that the organisms that get energy from organism X would need to rely on other sources of energy. Meanwhile, the population of organisms that are typically eaten by X may be able to grow more than they did while X was present.
    - What is the difference between 'food' and 'energy'? How do organisms (like us) get energy out of food? What happens to the energy in food during this process? What happens to the matter in food during this process?Within a closed system, both energy and matter are neither created nor destroyed. Energy and matter can be transformed (change from one form to another), but the total amount of each does not change. These transformations often occur at the molecular level so it can be hard to understand what is happening. Students will learn more about this while Atom Tracking!

Name: ___________________ Date: __________

Period: ________

Food Web Activity

In this exercise you will create a food web using organisms found in a pond eco-system. Access the food web tool at:

http://ecomuve.gse.harvard.edu/foodweb/foodweb.html

Click on "Pond" on the first webpage.

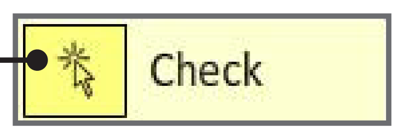
Learn more about which organisms eat which using the online Pond Field Guide. There is a link to the Field Guide within the food web tool.

Use the **"Drag"** tool to click on any organism and drag it onto the playing board.

Use the **"Connect"** tool to draw a connection between two organisms. Remember that the arrows in a food web represent the energy transfer between organisms. If organism A provides energy for organism B, the arrow will be drawn from organism A to organism B. For example, humans eat fish. Therefore, fish provide energy for humans.

Use the **"Check"** tool to check whether the connections you've made are correct. A correct connection will glow yellow; an incorrect connection will be black. You can click on the connection to learn more about what might be wrong.

Use the **"Disconnect"** tool to erase connections that are not correct.



See how many connections you can make!

When you are done creating your food web, print your final food web using the **"Print"** tool. If you do not have a printer, you may create a drawing of your final food web on a piece of paper.

Name: ___________________ Date: __________
Period: ________

Once you have a finished food web, answer the following questions.

1.) Name two of each type of organism from your food web:

Producers

Consumers

Decomposers

2.) Draw the longest food chain you found in your food web.

3.) Where does the energy in the food web come from?

Biotic and Abiotic Factors

Lesson 3

Summary

Students will learn about biotic and abiotic factors and use the Learning Quests to learn how to take water measurements. They will also discover the fish kill on July 28.

Understanding and Performance Goals

- Students should be able to notice, measure and document changes in both biotic and abiotic factors over time.

Time

- 40 min. (20 min. at the computer)

Materials

- Flipcharts, whiteboard, chalkboard or projector
- Computers with Internet access, ideally one per student
- Learning Quest Worksheet

Advanced Preparation

Note: A tutorial video on the Learning Quests is available on the EcoMUVE website download page.

1. Write the Learning Quest webpage address on the board so that all students can see it.
2. Print copies of the Learning Quest Worksheet.
3. Write Biotic and Abiotic on the board.
4. Set up computers.
5. Practice using the calendar tool, population tool, weather tool, and the water measurement tools.

Analyze (7 min.)

During the first two lessons students may have focused largely on the biotic parts of the ecosystem (the organisms that live there). Today they will learn about other tools that will help them measure and monitor the abiotic parts of the ecosystem.

1. Have the students help you list biotic and abiotic parts of the ecosystem they have observed. Explain that scientists are interested in understanding both abiotic and biotic parts of the system. Why?

2. Ask students to describe what a scientist does.
    - What types of scientists explore ecosystems? (Ecologists, water chemists, biologists)
    - What tools might they use to study the ecosystem?

Expand (8 min.)

1. Introduce the water measurement tool. The water measurement tool can help them measure temperature, dissolved oxygen, phosphates, nitrates, turbidity, pH, and chlorophyll a. All of these are abiotic variables that are important water-quality indicators. Demonstrate the use of the water measurement tools by using the overhead projector.

2. You may want to demonstrate these aspects of the virtual world to the students using the projector before allowing students to work on their own computer.
    - Show students the calendar tool. Explain that they will be able to visit Scheele Pond on eight different days over two months and collect data about how things change over time.
    - Show the population tool and have them think about how the populations of organisms might change over the summer.
    - Have students look at the weather tool. Remind students that weather can affect both biotic and abiotic aspects of an ecosystem. Wind may mix the pond while changes in temperature may affect the behavior of fish or other organisms.
    - Show them the data view table and the data graphs. All data they collect in the virtual world will be saved in their data table. This data will be available next time students open their file.

3. Students can learn more about the meanings of these water measurements using the Learning Quests. Demonstrate how to use the Learning Quests. Go to http://ecomuve.gse.harvard.edu/Pond_LQ.html

Note: It is up to you to decide if each student will need to complete all of the Learning Quests. Some teachers just require students to do the learning quests *specific to their roles, which are assigned in lesson 4. Students may complete these quests at their own pace, but must complete them before the end of Lesson 6.*

You may hand out the Learning Quest Worksheet today, or wait until Lesson 4. Students should complete this worksheet as they work through the Learning Quests. It also serves to document their completion of the task. They should hand it in when they have completed all of the Learning Quests.

Explore (20 min.)

1. Now that students have new tools to use, the classifications of biotic and abiotic factors, as well as consumers, producers, and decomposers, they may explore the world a little differently with a thought to relationships between the things that they see. As you move around, ask them to speculate about those relationships.

2. When there are a few minutes left, instruct everyone to use their calendar tool to go to July 28th and make note of their observations.

Review, Extend, Apply (5 min.)

1. Ask students to share how the new tools helped them make new discoveries. Have them share some of those observations.
    - What happened on July 28th? Explain that students will need to act like scientists to examine the ecosystem at Scheele Pond to try to determine what caused the fish to die.
    - What questions do students have for their next trip to Scheele Pond? What are they going to look for?

Name: ___________________ Date: __________
Period: ________

Learning Quests

1. Access the Learning Quests by visiting http://ecomuve.gse.harvard.edu/Pond_LQ.html
2. After you have completed each Learning Quest, complete the information below.

Chlorophyll – "What does GREEN mean?"

"… the_____________the water is, the more chlorophyll is in it."
"…chlorophyll is a molecule found in____________and___________that absorbs ____ ."
"Now we know that greener water means more ________________ , which means more algae!"

Oxygen – "Oxygen Oracle"

"You have learned two ways that oxygen gets into the water: photosynthesis and ________________________."
"And two ways that oxygen may be removed from the water: __________________ and warm temperatures."

Turbidity – "Seeing through the Haze"

"We found out that turbidity measures how_________________the water is."
"High turbidity means there is more material like algae,___________________ and _____________in the water and less ______________ can pass through."

pH – "Acids and Bases"

"Now, I know that when the pH is too high or too low it can be harmful for my ______________. A neutral pH around_______ , is just right."

Nitrates and Phosphates – "Nutrient Knowledge"

"Now I know that both Nitrates and ______________ help plants to grow bigger because they are __________________ for the plants."

Bacteria – "Bacteria Quest"

"Thousands of species of bacteria fill the soil. Most are______________ . They break apart ________________ so that the same ______________ can be used again by plants."

Science Team Roles

Lesson 4

Summary

Students will be grouped into teams of four and each member will take on a unique scientific role to help their team determine what may have caused the fish to die. The four roles include microscopic specialist, water chemist, private investigator, and naturalist. They will explore the pond ecosystem through the eyes of their scientific role, and will use their role sheets to find important information.

Understanding and Performance Goals

- Students should know their role on the team and understand the expectations of their role.

Time

- 40 min. (20 min. at the computer)

Materials

- Flipcharts, whiteboard, chalkboard or projector
- Computers, ideally one per student
- Group Worksheet
- Individual role sheets

Advanced Preparation

1. Determine how you are going to assign students to teams and determine team roles (determined by you or by the team).
2. Reproduce Group Worksheet – one copy per group.
3. Reproduce Role sheets .

Analyze (12 min.)

1. Group students in their science teams and have them discuss why they think the fish died. Have each team brainstorm at least 4 ideas about why the fish might have died. Encourage students to think about what kind of evidence they will need to collect in order to support or reject their ideas. They can use the group role worksheet to record their ideas.

Expand (8 min.)

1. Explain that students will be working in teams to look for evidence to help explain why the fish died. In order to ensure that every possibility has been considered, students will be asked to take on a different role that looks for specific things at Scheele Pond.

2. Discuss the responsibilities of each of the team roles.
    - **Microscopic specialist:** The microscopic specialist will look for creatures that live in our environment but are difficult to see. Using the submarine tool and the atom tracker tools, they will search the microscopic world for clues to help us understand why the fish died.

    - **Private investigator:** The private investigator will interact with the characters to learn more about the environment. People are dynamic factor in our world and they can also help us understand what is happening in the ecosystem by sharing not only what they did, but also what they experienced by seeing, hearing, feeling, or smelling.

    - **Water Chemist:** Water chemists use the water measurement tools to find out what is changing in the water over time. Water is like air to fish and there is a dynamic system underwater.

    - **Naturalist:** The naturalist will be looking at the different animal species, checking their population changes, and looking at other factors that might explain changes to the populations. The population tool and the water measurement tools will be useful in this role.

3. Explain how students may load teammates' data into their own data view. They will be working together on a team and will be sharing their data. All teammates must work hard to collect their own data so that the team has the data they need.

4. All teams must decide who will do each role. This information should be recorded on the group worksheet. Teachers may leave this decision to the students, or simplify the process by assigning student roles before class begins.

Explore (20 min.)

1. Have students move to their computers.

2. Using their role sheets, have students explore Scheele Pond to find the key information on their sheets. They do not have to finish their sheets today. They can write notes on the role sheets, or collect data into their data table.

Review, Extend, Apply (10 min.)

1. Optional: Have students get into groups with their same role and have them discuss and compare their findings and share tips of how they found certain things. Where are areas that are more difficult to complete?

Group Members' Names: Date: _________
______________________________, ______________________________, Period: _______
______________________________, ______________________________

Group Role Worksheet

Your goals for today are to:

1. Work as a group to brainstorm ideas about what happened to the fish.
2. Make a list of what your team knows and needs to find out in order to test the ideas on your brainstorm list.s
3. Come up with a plan for the group to make sure you collect the data you need!

Pick someone in the group to record at least four of your group's ideas about why the fish might have died here:

What We Know (clues we've already collected):

Now, as a group, make a list of the pieces of information you have that might be clues about why the fish died. Things in this list might be measurements you have collected or clues that characters told you.

What We Need to Find Out (other data we need to collect):

Think about things that you need to find out in order to test your ideas about why the fish died.

Who's Going to Do It:

List the name of the group member who is going to be in charge of getting each piece of data or information. Make sure each group member knows what he or she has to find out so you can get your research done.

Microscopic Specialist: _________________________, Naturalist: ____________________,

Water Chemist: _____________________, Private Investigator: _____________________

Name: ____________________

Date: __________
Period: ________

Private Investigator

(Learning Quests: What does Green mean? And Nutrient Knowledge)

There are a number of important clues hidden in the virtual world. Some places you will want to look for clues are listed below.

What can you learn from the people who live near the pond? Be sure to talk to:

- Manny on June 30th
- Mr. Mulligan on July 25th
- Ms. Vasquez on July 16th
- Ranger Susan on July 28th and August 15th

What is the weather like on different days? Use your weather measurement tools to find out!

How much chlorophyll a is there in the water on different days? Use your water measurement tools to find out!

What is the temperature of the water on different days? Use your water measurement tools to find out!

Does the amount of nutrients in the water (like phosphates and nitrates) change over time? Use your water measurement tools to find out!

Name: ___________________

Date: _________
Period: _______

Naturalist

(Learning Quests: Seeing through the haze and Oxygen Oracle)

There are a number of important clues hidden in the virtual world. Some places you will want to look for clues are listed below.

Does the number of organisms in the pond change over time? Use the population tool to find out! You can find population data for largemouth bass, bluegill, fathead minnows, green algae, bluegreen algae, and bacteria.

What can you learn about the different fish species? Check the field guide to find more information!

What happens to the carbon atom (especially on July 10th, July 16th, and August 15th)? Track that atom to find out!

Does the turbidity of the water change over time? Use your water measurement tools (and your eyes!) to find out!

Are there different amounts of dissolved oxygen in the pond on different days? Use your water measurement tools to find out!

Name: ___________________

Date: _________
Period: _______

Microscopic Specialist

(Learning Quests: What does Green mean? And Oxygen Oracle)

There are a number of important clues hidden in the virtual world. Some places you will want to look for clues are listed below.

How do the populations of the smallest organisms change over time? Use the Submarine to find out! You can monitor the population size of bluegreen algae, green algae and bacteria.

What happens to the oxygen atom (especially on July 25th and August 15th)? Track that atom to find out!

How much dissolved oxygen is there in the pond water on different days? Use your water measurement tools to find out!

Does the temperature of the water change over time? Use your water measurement tools to find out!

How much chlorophyll a is there in the water on different days? Use your water measurement tools to find out!

Name: ___________________ Date: _________
Period: _______

Water Chemist

(Learning Quests: Nutrient Knowledge and Acid or Base?)

There are a number of important clues hidden in the virtual world. Some places you will want to look for clues are listed below.

Are there different amounts of nutrients in the pond (phosphates and nitrates) on different days? Use your water measurement tools to find out!

What happens to the phosphorus atom (especially on July 25th, July 28th and August 15th)? Track that atom to find out!

Is the pH in the water different on different days? Use your water measurement tools to find out!

What happens to the carbon atom (especially on July 10th, July 16th, and August 15th)? Track that atom to find out!

Ecosystem Processes at the Atomic Level

Lesson 5

Summary

Students will learn what an atom is and understand its role in an ecosystem by completing the atom tracker worksheets and answering the atom tracker questions.

Note: This lesson may be done with or without computers. If using computers, students should be encouraged to use the Atom Tracker tool and find the atoms within the world on each calendar day; if not using computers, or if students have trouble finding the atoms, you may choose to reproduce the Atom Tracker comic strips, which show the information for each atom on each day. Alternatively, you may choose to use the comic strips for on-screen class presentation.

Depending on your choices and your students' background knowledge, you may choose to spend more than one day on this activity.

Understanding and Performance Goals

- Students will understand that atoms are neither created nor destroyed (the principle of conservation of matter).
- Students will understand that, through ecological processes, molecules can be broken apart and atoms rearranged to form different molecules.
- Students will understand that atoms by themselves are abiotic, but through the processes of photosynthesis and respiration, atoms become a part of living things (there is a strong relationship between abiotic and biotic parts of an ecosystem).

Time

- 40 min. (15 min. *optional* on the computer)

Materials

- Overhead, whiteboard, chalkboard, or projector
- Computers (optional)
- What is an Atom handout (optional)
- Atom Tracker Worksheets – Oxygen, Carbon, and Phosphorus
- Atom Tracker Reflection Questions

- 3 Atom Tracker Comic Strips that allow students to see the path of carbon, phosphorus and oxygen through the virtual world.
- Overhead markers

Advanced Preparation

1. Reproduce "What is an Atom?" if needed – 1 copy per student.
2. Reproduce Atom Tracker Worksheets – 1 copy of each per student.
3. Reproduce Atom Tracker Reflection Questions – 1 copy per student.
4. Reproduce copies of the 3 Atom Tracker Comic Strips found on the EcoMUVE download webpage (Optional – see note above.)
5. Review the Atom Tracker tool and the comic strip to be sure that you have a sense of where the atoms are in the ecosystem. Appendix D also describes the locations and text of each atom on each calendar day.
6. Consider using this website for a great simulation of powers of ten down to a carbon atom: http://learn.genetics.utah.edu/content/begin/cells/scale/ or the video Powers of Ten (e.g., http://youtu.be/0fKBhvDjuy0), or similar.
7. Consider including a discussion of the carbon cycle – if desired, find or create representations of the phosphorus and oxygen (see discussion notes below).

Analyze (3 min.) *(15 min. if this is new content)*

1. Ask "What is an atom?" If this is new content for your students, then share the handout "What is an Atom?" and discuss as a class. You may want to include the website or video above.

2. Demonstrate the Atom Tracker Tool in EcoMUVE, if your students have not already used it. When students click on the Atom Tracker icon on the tool bar, the icon is highlighted to indicate that the Atom Tracking device is active. This means the Atom Tracking signs will be visible in the world. Students will be able to track three different atoms: Carbon, Phosphorus and Oxygen. On each simulated day the students should be able to find the Atom Tracker icon and read a description of what has happened to the atom since the student last saw the atom.

Expand (15 min.)

1. Hand out all three atom worksheets to each students. Have each student select an atom to track (carbon, phosphorus, or oxygen). Have students work on the computer (or using the Atom Tracker comic strips) to complete the worksheet for their atom.

   Note: Students may not understand how to answer the question "Kind of Molecule." A careful reading of each atom tracker message should include that information.

2. If students have completed the Atom Tracker Worksheet for their atom they may look for the other two atoms, or work on the Atom Tracker Reflection Questions.

Explore (20 min.)

1. Conduct a whole-class discussion. Invite individual students to share what happened to their atom on each day. During this sharing, students who did not track that atom should fill in the answers on their worksheets.

2. Have a class discussion around how the activities of the atoms fit in with the elemental cycle for each atom. You can connect the activities of the individual atoms to the larger elemental cycle of which the atom is a part. For example, we provide a diagram of the carbon cycle below. A teacher-led discussion of the carbon cycle diagram may help students see the processes that are involved in transformation of carbon dioxide in the ecosystem. In the EcoMUVE world or comic strip version, students will observe carbon in some, but not all of these forms (they won't find emissions or ocean uptake). Encourage students to discuss the ones they noticed. Which parts of the cycle

are in the virtual world even though they are not explicitly mentioned (e.g., organic carbon, root respiration)?

3. Try using a colorful marker and overhead projector or project the diagram onto a white- board to trace the path of the atom. You can do the same with the phosphorus and oxy- gen cycle (diagrams not provided). Completing this exercise with multiple atoms will help the students see similarities among the atoms. In particular, comparing carbon and oxygen Atom Tracker routes will show that both carbon and oxygen are parts of glucose, starch, and carbon dioxide molecules.

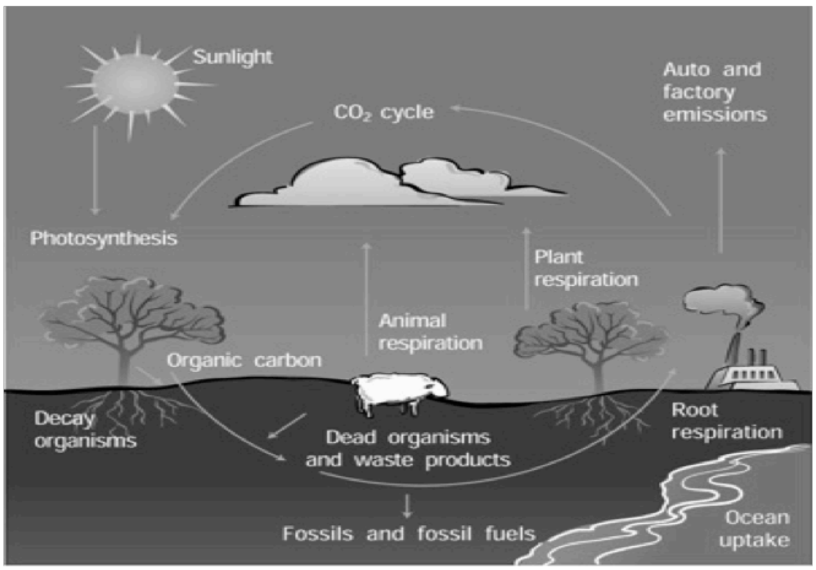
4. Probe students' understanding by asking questions like:
    - *"Where do atoms come from?"* Most of the atoms on Earth have been here since the Solar System was formed.
    - *"Can atoms be destroyed?"* Atoms cannot be destroyed or created; instead, atoms are rearranged to form different molecules.
    - *"How do atoms move from one part of the ecosystem to another?"* Atoms can be transported very far distances. Dust from the Sahara desert has been found in South America and the Alps in Europe. It is transported from Africa by the wind. Discuss other ways we saw atoms moving around the ecosystem.
    - *"What kinds of ecological processes did your atom go through?"* Ecological processes are the chemical, physical and biological changes that can happen to matter in an ecosystem. Examples are photosynthesis, respiration, decomposition and transport.
    - *"What is the difference between an atom and a molecule?"* An atom is the smallest unit of a single type of matter. A molecule is any combination of more than one atom. Molecules may be made of only one kind of atom. For example oxygen atoms are usually bound in pairs, that is why they can be represented as O2.
    - *"What different molecules were your atoms a part of?"* Some examples are starch (O and C), carbon dioxide (O and C), oxygen (O), water (O), glucose (O and C), phospholipid (P), and phosphate (P).
    - *"Are atoms living or non-living?"* Atoms are non-living, but through the processes of photosynthesis and respiration, atoms are combined into the molecules that make up all living things. Through other processes, such as decomposition, atoms can go from being part of a living thing to being non-living parts of the soil or water.
    - *"How many carbon atoms do you think there are in the ecosystem around Scheele pond? Do you think all of the carbon atoms are doing the same thing as the atom on the worksheet?"* There are far too many atoms in an ecosystem to have any hope of estimating the number. There are many, many carbon atoms in the ecosystem and they are parts of many different molecules, many different organisms and they go through many different processes.

5. If you have extra time you could have the students construct their own story about what happened to a different atom in the ecosystem near Scheele Pond

Review, Extend, Apply (2 min.)

1. Explain that students should think about how atoms played a role in the Scheele Pond ecosystem, and how the processes may be related to the fish kill.

Carbon Cycle



Name: ________________ Date: ________
Period: _______

What is an Atom?

Atoms are the smallest unit of matter. Atoms are the building blocks that make up matter. Atoms combine to form molecules. Atoms and molecules combine to form both living and nonliving things.

The sandwich you had for lunch is matter and is made up of atoms and molecules. Think about breaking that sandwich down into smaller and smaller bits - so small you need a fancy microscope to see them. When we break the sandwich down into the smallest bits, those bits would be atoms. Your sandwich was made up of millions of atoms.

The air you just breathed in is also made up of atoms and molecules. Even though you cannot see the air, it contains oxygen, nitrogen and carbon dioxide, along with other atoms and molecules.

To give you an idea of how big an atom is, imagine an apple. If we think about how small an apple is compared to the size of the entire Earth, that is similar to how small an atom is compared to an apple.

There are only 92 kinds of atoms that exist naturally on earth. These are called elements, and you can find them in a periodic table. Amazingly, these 92 kinds of atoms can be combined in many, many ways to make up all of the things around you.

Atoms are non-living, but when they are combined in just the right way, atoms make up living things. So, even tiny cells that are the smallest part of a living organism are made up of atoms.

How does this all happen? How can non-living atoms combine to form all the living and non-living things around you? Think about these questions as you try out the Atom Tracker tool!

Atom Tracker Carbon

Name:________________________

Use this worksheet to follow the Carbon Atom through the world. Use the dates and images as hints to help you find the atom in the world. Record **where** you found the atom and the **kind of molecule** it was in. Fill in the spaces with details about the atom.

1 JUNE 30

Where: __________

Kind of Molecule:

____

What is this plant?

____

2 JULY 6

Where: ____________________

Kind of Molecule: _________________

What is at the bottom of the pond?

____

3 JULY 10

Where:

____

Kind of Molecule: _________________

When bacteria break apart molecules in dead plants and animals it is called

____

4 JULY 16

Where: ____________________

Kind of Molecule: __________________

When organisms use oxygen to break apart glucose and starch for energy it is called _____________________

5 JULY 22

Where: ____________________

Kind of Molecule: __________________

6 JULY 25

Where: ____________________

Kind of Molecule: _____________

When plants use sunlight to turn carbon dioxide and water into glucose and oxygen it is called

____

7 JULY 28

Where: ____________

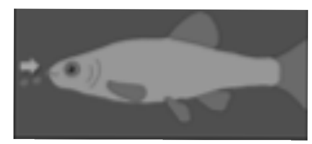
Kind of Molecule:

____

Plants combine _________ molecules to make larger starch molecules, like in this plant:

____

8 AUGUST 15



Where: _______________

Kind of Molecule: __________

What happened in the minnow to break down the starch?

____

Atom Tracker Oxygen

Name:______________________

Use this worksheet to follow the Oxygen Atom through the world. Use the dates and images as hints to help you find the atom in the world. Record **where** you found the atom and the **kind of molecule** it was in. Fill in the spaces with details about the atom.

1 JUNE 30

Where: ____________

Kind of Molecule: ____________

Getting close to this part of the tree: ____________

2 JULY 6

Where: ____________

Kind of Molecule: ____________

Traveled to this part of the tree: ____________

3 JULY 10

Where: ____________

Kind of Molecule: ____________

During ____________ plants use sunlight to turn carbon dioxide and water into glucose and oxygen molecules.

4 JULY 16

Where: ____________

Kind of Molecule: ____________

The wind mixed the oxygen molecule into the pond. Now it is called ____________ oxygen.

5 JULY 22

Where: ____________

Kind of Molecule: ____________

Gets into the fish's bloodstream through its ____________.

6 JULY 25

Where: ____________

Kind of Molecule: ____________

During ____________ the fish's cells use oxygen to break apart glucose for energy.

7 JULY 28

Where: ____________

Kind of Molecule: ____________

The elodea plant links glucose molecules together to make ____________

8 AUGUST 15

Where: ____________

Kind of Molecule: ____________

Plants and animals both do ____________.

They use oxygen to break apart glucose and starch for energy.

Atom Tracker Phosphorus

Name: ______________________

Use this worksheet to follow the Phosphorous Atom through the world. Use the dates and images as hints to help you find the atom in the world. Record **where** you found the atom and the **kind of molecule** it was in. Fill in the spaces with details about the atom.

1 JUNE 30

Where: ____________

Kind of Molecule: ____________

What is this seed? ____________

2 JULY 6

Where: ____________

Kind of Molecule: ____________

What happens in the squirrel's stomach? ____________

3 JULY 10

Where: ____________

Kind of Molecule: ____________

What happens in the squirrel's kidneys? ____________

4 JULY 16

Where: ____________

Kind of Molecule: ____________

5 JULY 22

Where: ____________

Kind of Molecule: ____________

Taken up by this plant: ____________

6 JULY 25

Where: ____________

Kind of Molecule: ____________

When there is sunlight during the day, phosphorus helps with ____________

7 JULY 28

Where: ____________

Kind of Molecule: ____________

The algae cell was eaten by a ____________

8 AUGUST 15

Where: ____________

Kind of Molecule: ____________

____________ absorbs phosphate molecules in the water and uses them to grow.

Name: __________________ Date: _________
Period: _______

Atom Tracker Reflection Questions

After you track one atom through the environment, answer these questions.

1.) Which atom did you track?

2.) What ecological processes did your atom go through? Ecological processes are the chemical, physical and biological changes that can happen to matter in an ecosystem. Examples are photosynthesis, respiration, decomposition and transport.

3.) What organisms was your atom a part of?

4.) Imagine all of the atoms in a pond ecosystem at the beginning of the summer (June) and at the end (August). During the summer, atoms may be parts of different molecules, and may become parts of different organisms, may participate in photosynthesis and respiration. At the end of the summer, do you think there are more, less or about the same number of atoms in the ecosystem as at the beginning of the summer? Explain your answer.

Ecological Processes

Lesson 6

Summary
Students will learn how what they learned about atoms relates to ecological processes like photosynthesis, respiration, and decomposition. They will get into their teams and look at trends in the data and as a class discuss how the atom tracker experience may help explain some of those trends.

Understanding and Performance Goals
- Students will connect what they learned about atoms to ecological processes like photosynthesis, respiration and decomposition and to changes they have observed in the water measurement tools.

Time
- 40 min. (15 min. at the computer)

Materials
- Overhead, whiteboard, chalkboard, or projector
- Computers, ideally one per student
- Atom Tracker Worksheets, Comic Strips and Reflection Questions

Advanced Preparation
1. Review the Atom Tracker sheets to be sure that you have a sense of where the atoms have been in the ecosystem.

Analyze (10 min.)

1. Ask students to get into their scientific teams and share what they discovered in their role. They should gather around one computer and compile the data they collected into a single data table. Students should look for trends in the graphs over time or note gaps in the data. They should decide as a group what other evidence needs to be collected in order to explore the hypotheses they brainstormed during Lesson 4.

Expand (15 min.)

1. Conduct a whole-class discussion:
    - How do the trends you see in your graphs relate to the Atom Tracker experience?
    - The Atom Tracker for oxygen and phosphorus can give hints about why these variables are changing over time (photosynthesis, respiration, decomposition, uptake of nutrients)
    - Ecological processes are the processes by which atoms can be rearranged into different molecules.
    - What ecological processes did your atom participated in?
    - If students have not been exposed to details about the processes of photosynthesis and respiration, review these concepts. If students have previously learned about photosynthesis and respiration, the remainder of this class period may be used to collect data.

2. Have students move to their computers.

Explore (15 min.)

1. Students have the remainder of the class period to collect data. They should focus on collecting data and evidence according to the team discussion at the beginning of the period. Students should be close to completing their data collection by the end of this session.

2. Because each role is responsible for collecting different data, show students how they can share their data with their team. To import student B's data into Student A's file, transfer Student B's file to Student A's computer, then have Student A import Student B's file by clicking the 'Import' button that is part of the data inspector tool. Student B's data will automatically be saved into Student A's file.

For a more detailed explanation of this process, watch the video tutorials on the EcoMUVE website.

What are Causal Relationships?

Lesson 7

Summary

Students will learn how to represent complex relationships using a concept map with a real life example. Students will begin to construct a concept map of what caused the fish to die in EcoMUVE with their team.

Understanding and Performance Goals

- Students will understand how to represent complex relationships using a concept map.

Time

- 40 min. (no time at the computer)

Materials

- Overhead, whiteboard, chalkboard or projector
- Large sheets of paper for draft concept maps
- Parachuting Cats into Borneo Story

Advanced Preparation

1. Print off a copy of the Parachuting Cats into Borneo Story to read to the class.

Analyze (15 min.)

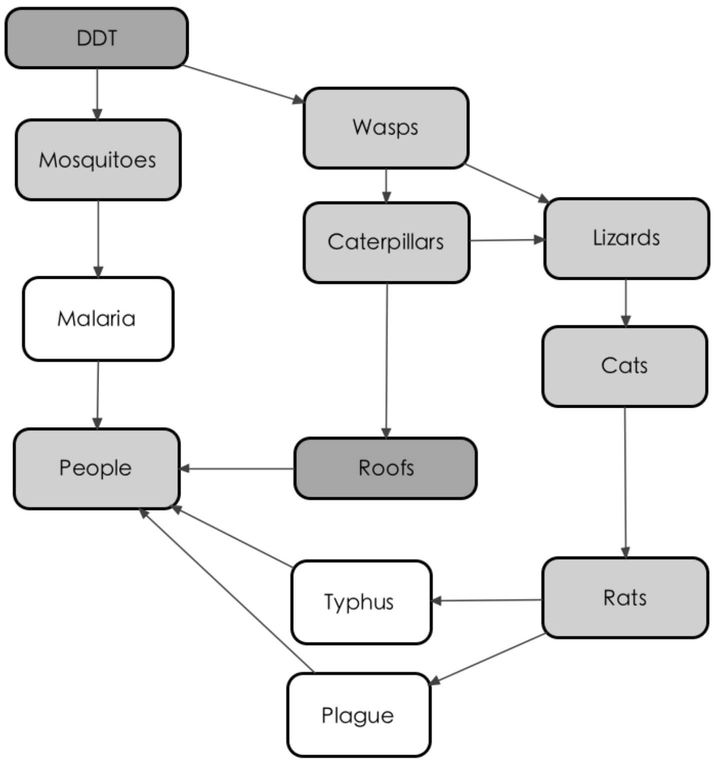
1. Explain that in the EcoMUVE mystery, the explanation for what caused the fish to die is not simple. It is up to the teams to discover why the fish died. They will learn about a mystery that occurred in Borneo.

2. Tell the story of cats parachuting into Borneo and, after you tell the story, have the class help you construct a concept map that represents the relationships in the story. It works well to construct the concept map together on an overhead transparency, white board, smartboard, or large piece of paper.

3. Your map may look similar to the one on the right.

4. The conclusion from the story should be that relationships in ecosystems are complex and that when there is a change in the ecosystem it can often lead to unintended consequences.

Parachuting Cats into Borneo:Causal Map



Explore (20 min.)

1. Instruct students to create a similar concept map for what they think is happening to the fish at Scheele Pond. It may be challenging for the students to know where to start on their own concept map. You can encourage them to remember your conversation on days one and two. Think about all the biotic and abiotic components of the ecosystem. How do these fit together in a concept map?

2. Also, encourage students to think about the fish kill. They may want to start their concept map with a box that represents fish and then think about all the other parts of the ecosystem that connect with or affect fish.

3. We expect that students will be able to recognize that a relationship exists between two components of the ecosystem. The resulting concept map should look like a web of relationships between both biotic and abiotic components of the ecosystem.

4. You should review the concept maps before the next class to determine which components and connections are represented. Assessment of these concept maps can help the teacher identify any concepts that need additional instruction.

Review, Extend, Apply (5 min.)

1. In the final few minutes have students turn in their causal maps. Have students share some of their discoveries.

Misconceptions or Gaps

The concept maps may reveal misconceptions or gaps in student understanding. A quick review of the concept maps can alert you to some common misconceptions. You can address these during the remaining class periods by drawing students' attention to relevant evidence in the virtual world.

- If concept maps reveal that students are not picking up on important microscopic organisms (e.g. algae and bacteria), point out the importance of collecting population data for microscopic species. Make sure students know how to access and use the submarine tool.
- If concept maps reveal that students do not recognize the importance of the decline in dissolved oxygen, lead them through an activity focused on the relationship between respiration, photosynthesis, and the amount of oxygen required for different types of organisms. They may want to review the Learning Quest for oxygen.
- If students have incorporated bacteria into their concept map and also reveal understanding of the relationship between oxygen and the fish deaths, then encourage them to work as a group to develop the graphs and evidence that they need to support the relationships they've identified in their concept map.

Parachuting Cats into Borneo

In the early 1950s, there was an outbreak of a serious disease called malaria among the Dayak people in Borneo. The World Health Organization tried to solve the problem. They sprayed large amounts of a chemical called DDT to kill the mosquitoes that carried the malaria. The mosquitoes died and there was less malaria. That was good. However, there were side effects. One of the first effects was that the roofs of people's houses began to fall down on their heads. It turned out that the DDT was also killing a parasitic wasp that ate thatch-eating caterpillars. Without the wasps to eat them, there were more and more thatch-eating caterpillars. Worse than that, the insects that died from being poisoned by DDT were eaten by gecko lizards, which were then eaten by cats. The cats started to die, the rats flourished, and the people were threatened by outbreaks of two new serious diseases carried by the rats: sylvatic plague and typhus. To cope with these problems, which it had itself created, the World Health Organization had to parachute live cats into Borneo.

Evidence to Support Causal Relationships

Lesson 8

Summary

Students will be asked to use the tables and graphs in EcoMUVE to find evidence that supports their theories of the causal relationships represented in the concept maps they developed about what caused the fish to die.

Understanding and Performance Goals

- Students should be able to interpret graphs of variables changing over time.
- Students should recognize the importance of using data and evidence to support a scientific claim.

Time

- 40 min. (20 min. at the computer)

Materials

- Overhead, whiteboard, chalkboard or projector
- LCD projector and screen, if available
- Computers
- Draft concept maps from previous day

Advanced Preparation

1. Reproduce the bluegill graph in Appendix C so that it can be viewed in class.
2. Review the graphs in Appendix C.

Analyze (5 min.)

1. If there were some common errors on the practice concept maps you may want to take some time to clarify misconceptions. See notes about Misconceptions or Gaps in Lesson 7.

2. Explain that we talked about causal relationships in the last session and saw that causes can be complex. Have students give a couple examples of causal relationships they identified at Scheele Pond. How do they know there is a relationship?

Expand (10 min.)

1. Explain how important it is to support their findings with evidence. Students might feel really sure about the reasons on their maps, but without evidence, it is little more than a hunch and not very believable.

2. Ask students to name the kinds of evidence they've collected in EcoMUVE. They should mention data on water measurements, populations, weather, learning quests, information from Manny or other people in the world, field guide, atom tracker and food web.

3. Help students see how data can be used to support their ideas about how things are related.

4. Take an example they have given you, like the relationship between big fish and small fish. Ask them how they know these two are related. Students may explain that they know that Big Fish eat Little Fish, or some may point to data. If students do not bring this up, prompt them with, "If these two are related, what would the data for these two variables look like over time?"

5. Show students the graph of largemouth bass and minnows using the graphing tool. The students should see that when largemouth bass go away, the minnow population increases.

Students can make inferences about the relationships between other variables based on the patterns they see in their graphs.

Students will see other patterns where peaks in one variable are followed by peaks in another related variable. For example, nitrates and phosphates in the pond go up followed by an increased in the population of algae. Because there is often a delay between a cause and effect, many of the causal relationships may fit this pattern. See Appendix C for more information explaining the changes over time.

However, two variables changing in a similar pattern on the graph does not *necessarily mean that the two variables are related.*

Explore (20 min.)

1. Encourage students to examine their graphs and try to support the relationships in their concept maps with both a *reason* and *data*. They can add on to their concept maps if the exploration of their graphs reveals additional relationships they had not thought about.

2. Students may return to their computers and continue to collect evidence that will support the relationships they've identified in their concept maps.

Review, Extend, Apply (5 min.)

1. Have a couple of students share a relationship they identified and the evidence they have to support their claim.

Building Cases

Lesson 9

Summary

Students will get into their groups and agree on a final hypothesis for what caused the fish to die, compile the evidence to support their hypothesis, and revise concept maps accordingly. Students will be expected to present their findings for the following lesson.

Understanding and Performance Goals

- Students will be able to work in groups to represent a final hypothesis for the team and create a group concept map.

Time

- 40 min (computers should be available for use)

Materials

- Flipcharts, whiteboard, chalkboard, or projector
- Computers, ideally one per student
- Large paper for concept maps
- Pens or colored markers
- A printer

Advanced Preparation

None.

Analyze (2 min.)

1. Return the draft concept maps to the groups.

Expand (10 min.)

1. Explain that students are going to put together a coherent argument about what caused the fish to die, and support their argument with evidence from the virtual world in their science teams. Each of the members of the team should be able to contribute a slightly different perspective and enrich their argument.
    - Groups will present their argument and evidence in class on the next day.
    - Each group will have about 5 minutes to present their ideas.
    - Students may present any of the following to support their ideas about what caused the fish kill
        1. Their group's concept map
        2. A print-out of graphs from EcoMUVE
        3. A visual representation of any other evidence (info from Atom Tracker, the Field Guide, Learning Modules, or characters in the world)
    - Groups may plan to divide their presenation by having each student explain the argument and evidence realting to their role.

2. Provide large pieces of blank paper on which students can write or draw components for their presentation. Encourage students to make any presentation materials easy to read – using large, clear printing.

Explore (25 min.)

1. Have students get into their science team groups and develop their concept maps. Students should support the connections with evidence. They may want to print copies of their graphs. If there is a printer in the classroom, this can be done using the print function on your web browser.

2. Circulate among the groups to help them develop their arguments.

Review, Extend, Apply (3 min.)

1. Ask students if they have any questions about the presentations that will happen on the following day.

Sharing Conclusions

Lesson 10

Summary

Student groups will present their finding to the class. Classmates are encouraged to pay attention during the presentations to listen for what evidence the presenters are providing and to ask questions.

Understanding and Performance Goals

- Students should be able to communicate a hypothesis and offer evidence to support their claim.

Time

- 50 min. (no time at the computer)

Materials

- Overhead, whiteboard, chalkboard, or projector

Advanced Preparation

1. Determine the order the groups will present in.

Expand (5 min.)

1. Explain that each group will have about 5 minutes to share their conclusions.

2. Tell the audience, your students, that it is their role to ask questions about what they are hearing.
    - Is the group making a clear argument?
    - What evidence have they provided?
    - Does it support the type of causal relationship the group is describing?

Explore (30 min.)

1. Have each group present their explanation and supporting evidence (5 minutes for each presentation, depending on the number of groups).

2. If student presentations are redundant, you may ask students to only present the information that is new or different from other groups. It may be useful to use material that each class is presenting to construct a large whole-class concept map that shows the relationships in the virtual world. This approach makes it easy to fill in gaps in the argument or point to redundancies. Support connections in the concept map by pinning up printed graphs that show the relationship.

Review, Extend, Apply (5 min.)

1. Wrap-up the class by discussing which evidence was most important. Which was hardest to get? Why was it difficult to put all of the pieces together? Is it likely that these kinds of causal features are present in a lot of ecosystems? Have the class come up with other examples where they have seen complex causal patterns in other systems.

Debriefing the Experience

Lesson 11

Summary

Students will be asked to reflect on and share how participating in this EcoMUVE investigation makes them think differently about cause and effect in the real world, and how causality ties in with other science lessons they have learned.

Understanding and Performance Goals

- Students will understand how complex causality occurs in areas beyond ecosystem science.

Time

- 40 min (no time at the computer)

Materials

- Overhead, whiteboard, chalkboard, or projector
- Sample causal pattern drawings

Advanced Preparation

None.

Analyze (5-10 min)

1. If there was not sufficient time to finish presentations and have a discussion during the previous class, conduct the wrap up discussion described in the Review, Extend, Apply section of Lesson 10.

Expand (10 min.)

1. Explain all the factors that helped cause the fish to die.

2. Go over student misconceptions that you may have noticed during the presentations. For example, some students may have noticed the increase in bacteria and assumed that bacteria killed the fish. In fact, it was the indirect reason that the bacteria used up too much of the oxygen in the pond and there was not enough for the fish.

Explore (10 min.)

- Can students think of cases where this phenomenon happens in real life and how to avoid it?
  A: For example, fish tanks use an aerator to mix oxygen into the water for the fish. Commercial fish farms also use aerators to keep the fish alive. Students might have heard about "dead zones" in the ocean on the news; these are similarly caused by excess nutrients causing algae blooms, and then bacterial decomposition leading to oxygen depletion. There's a very large dead zone is (approximately 8000 square miles, about the size of New Jersey) in the Gulf of Mexico, where the Mississippi River runs off into the ocean, carrying large amounts of runoff filled with nutrients washed in from the farms of the Midwest.

- Why do we not have to worry about running out of oxygen on land?
  A: Mainly because this is not a closed system like the pond. In the air, oxygen freely mixes all through the atmosphere. Fifty to seventy percent of the world's oxygen is produced via photosynthesis of phytoplankton in the world's oceans. The rest is produced via photosynthesis on land by trees, shrubs, grasses, and other plants.

Review, Extend, Apply (10-15 min.)

1. How does this experience make you think differently about cause and effect in the real world?
   - How can causality tie into other science lessons that the class has studied?
   - Introduce what the next science unit is and share how it is related to what they just learned.

Understanding Goals

Learning Objectives

The EcoMUVE introduces many ecosystems and causality concepts that students are expected to learn in Middle School and beyond. The tables below outline these concepts as well as their corresponding National Science Education Standards (NSES). How deeply your students learn the concepts depends upon how much time your class spends in EcoMUVE, the path that they take, and the supporting discussions that you engage them in.

Ecosystems Understanding Goals:

Food Webs and Energy Transfer:

1. A food web illustrates the energy transfer resulting from feeding relationships between organisms in an ecosystem.
2. All of the food energy in the food web can be traced back to the sun.
3. Plants provide a critical link to the sun by converting energy from the sun through a process called photosynthesis.
4. Energy from the sun is transferred throughout the food web via a domino-like pattern.
5. Most food webs have some stability and can recover from certain types of disturbances.

Microbes:

6. Microbes are tiny organisms that we cannot see without a microscope. This makes them less obvious to us.
7. There are many different kinds of microbes (for instance, photo-plankton, zooplankton, bacteria, and so forth) and they play many different kinds of roles in an ecosystem.

Measurement and Monitoring:

1. Understanding what is happening in an ecosystem involves measurement and monitoring.
2. We take measurements to help us gain precise information.
3. We can monitor changes in our measurements to consider the behavior of the system at steady state and also to help us to detect possible

changes "on the horizon."
4. We can use tools and various tests to monitor variables that we cannot see.

Populations and Communities:
1. Ecosystems have a large number of individual organisms belonging to different species.
2. A population is the total number of individuals of a single species in a specified area.
3. In a food web, some organisms (prey) provide food for other organisms (predators). The predators help to keep the prey population in balance. This is a type of two-way causal relationship.

Balance and Flux:
1. Ecosystems are dynamic and some amount of flux, or change, is natural.
2. Because of interdependencies in the ecosystem, the fates of the populations are linked. Events that affect one population typically have ripple effects—affecting other populations. When one population is out of balance, others may be too.

Thinking about Spatial Scale and Action at a Distance:
1. Effects in ecosystems are often "at a distance." This means that the causes and effects are not directly touching and so it requires more extensive searching—a broad view.
2. It can be hard to know where to draw the parameters of a system. This is a question that ecosystem scientists often debate.

Interaction between Biotic and Abiotic Worlds:
1. The living and non-living worlds interact.
2. Organisms display diverse responses to the factors within their environment—some organisms are more sensitive than others to physical, chemical, and biological conditions.
3. Environmental changes can sometimes be detected by changes in the behavior and numbers of certain organisms.
4. The law of limiting factors links population size of any particular species to the availability of resources. For instance, too little phosphorus in the soil and plant growth will be limited; too much and there will be overly abundant plant growth.

Matter Recycling:
1. When dead matter decomposes it does not disappear, but is recy-

cled through living things and the physical environment. The atoms are recycled.
2. When dead matter decomposes, it gets broken down into its basic elements, some of which are nutrients. Those nutrients are put back into the physical environment (soil, water, air) by decomposers.
3. Nutrients are passed along the food web from plants to animals, from animals to animals, from dead plants and animals to decomposers, and finally back to plants via soil, air and water.
4. The matter cycle (of producers to consumers to decomposers back to producers, and so on) is crucial to the rest of the food web and the ecosystem as a whole. If organisms did not decompose, essential elements would remain "locked up" in those organisms and would be unavailable for new life.

Decomposers:

1. "Decomposers" are organisms that cause things to decay or "break down" by eating or digesting organic matter.
2. Some decomposers, such as earthworms, are more obvious to us than others because they are visible without a microscope.
3. Some decomposers are microbes, such as bacteria; microbes are tiny organisms that are typically too small to see with just your eyes, and thus are less obvious to us.
4. Microbes do most of the decomposition.

Photosynthesis:

1. Plants convert energy from the sun to food energy through a process called photosynthesis.
2. Photosynthesis is a photochemical process that requires light to convert carbon dioxide and water to carbohydrates, starch, and sugars.
3. It can be difficult to think of plants as getting their food from the sun because that involves "action-at-a distance" and you can't see the components of the process. So we revert to thinking that plants get their food from soil, a more tangible cause (food and nutrients get sucked up by the roots) with a tangible process (that touches the roots of the plant.)

Causality Understanding Goals

Domino Causality:

1. Causes have direct and indirect effects.
2. Causes can have far-reaching effects.
3. In domino causality, one effect leads to another and so on. Domino causality can include branches where a cause can lead to more

than one effect and so on.

Obvious and Non-obvious Causes:

1. There are obvious and non-obvious causes.
2. We often are unaware of microbes and don't attend to them. Mentally "zooming in" to the microscopic level can help us to consider microbes in our causal analyses.
3. When causes are not obvious, it can make it harder to see causal patterns, such as the cyclic causal pattern involved in decay.

Attending to Steady States:

1. Our attention is drawn to things that "break through" the normal state of affairs. This means that we tend to notice "event-based causality."
2. Often it is important to attend to the on-going status of a system. Scientific tools and processes, as well as systems that are designed to monitor processes for us, can help.

Distributed and Emergent Causality:

1. Some causes are bottom-up. They generate from the interactions of many individual actions instead of a centralized and single source.
2. It can be complex to predict how minor changes at the level of individual behavior will lead to emergent behaviors at the population level.

Reasoning about Systems Dynamics:

1. Systems behave very differently when one or more aspect is out of balance. One aspect can affect other aspects of the system. If one population becomes unstable and its numbers begin to oscillate widely, others typically become unstable too.
2. Some events do not have strong or direct adverse effects on the system because of insurance built into the system.
3. Events often "grab" our attention but reasoning about systems involves thinking about the system dynamics, and moving beyond managing events.
4. Understanding balance and flux is impacted by how we reason about time. Systems might look unbalanced in instances of "snap shot" reasoning yet if we look more continuously using "video reasoning," they appear balanced in the longer term.

Spatial Gaps, Scale, and System Boundaries:

1. We tend to look for spatially local effects and to be efficient in our searching for effects. It is important to question where we draw the boundaries when thinking about ecosystems relationships.
2. When reasoning about Domino Causal Patterns, we often need to

broaden the boundaries of the system.

3. One form of causal reasoning involves constraint-based reasoning. This means reasoning about the limits that constrain the system.

Cyclic Causality:

1. In cyclic causality, there is no real beginning or ending.
2. There are cycles of decay happening simultaneously all of the time. There will always be nutrients being made available in the ecosystem.

Alignment with Standards

National Science Education Standards (NSES)

Life Science (Content Standard C)

Populations and Ecosystems

- A population consists of all individuals of a species that occur together at a given place and time. All populations living together and the physical factors with which they interact compose an ecosystem.
- Populations of organisms can be categorized by the function they serve in an ecosystem. Plants and some micro-organisms are producers; they make their own food. All animals, including humans, are consumers, which obtain food by eating other organisms. Decomposers, primarily bacteria and fungi, are consumers that use waste materials and dead organisms for food. Food webs identify the relationships among producers, consumers, and decomposers in an ecosystem.
- For ecosystems, the major source of energy is sunlight. Energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis. That energy then passes from organism to organism in food webs.
- The number of organisms an ecosystem can support depends on the resources available and abiotic factors, such as quantity of light and water, range of temperatures, and soil composition. Given adequate biotic and abiotic resources, and no disease or predators, populations (including humans) increase at rapid rates. Lack of resources and other factors, such as predation and climate, limit the growth of populations in specific niches in the ecosystem.

Science in Personal and Social Perspectives (Content Standard F)

Populations, Resources, and Environments

- When an area becomes overpopulated, the environment will become degraded due to the increased use of resources.
- Causes of environmental degradation and resource depletion vary from region to region and from country to country.

Natural Hazards

- Human activities can also induce hazards through resource acquisi-

tion, urban growth, land-use decisions, and waste disposal. Such activities can accelerate many natural changes.
- Natural hazards can present personal and societal challenges because misidentifying the change or incorrectly estimating the rate and scale of change may result in either too little attention and significant human costs or too much cost for unneeded preventive measures.

Changes in Scheele Pond Over Time

Time Graphs

This appendix contains graphs that show the changes in water variables, weather variables and organism populations over time. If students collect all of the data that are available in the pond, they will be able to see graphs that look like these. The appendix contains information about why the patterns in the graphs look the way they do.

Instructors can download the Pond-Forest Master Data.eco file from the EcoMUVE downloads page. This file contains the data in the tables below:

Master Data

Water Measurements

	June 30	July 6	July 10	July 16	July 22	July 25	July 28	Aug 25
Temperature (^{0}C)	22	19	21.5	24.5	26.5	27.5	25.5	25
Oxygen (mgL)	8.4	9.5	9.4	10.2	5.4	4.1	7.3	8.4
PO_4 (mgL)	0.01	0.1	0.03	0	0.015	0.018	0.035	0.025
NO_3 (mgL)	0.15	0.56	0.33	0.21	0.11	0.2	0.3	0.28
Turbidity (NTUs)	5	25	35	65	25	10	15	30
pH	7.2	6.7	8	8.4	7.3	7.2	7.6	8.2
Chlorophyll a (ugL)	20	10	50	100	30	10	15	30

Weather Measurements

	June 30	July 6	July 10	July 16	July 22	July 25	July 28	Aug 25
Air Temperature (^{0}C)	25.5	20	24.5	26.5	31	34	27.5	26.5
Wind Speed (m/s)	1.5	4.5	3	2	1.5	0	3.5	2
Cloud Cover	40	100	0	20	100	100	10	20

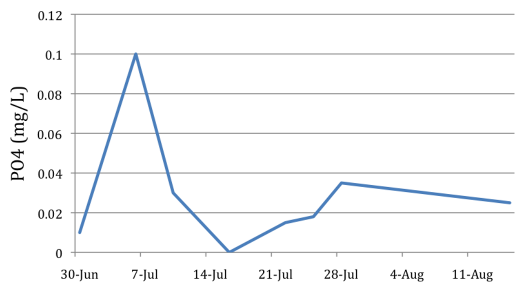
Population

	June 30	July 6	July 10	July 16	July 22	July 25	July 28	Aug 25
Bacteria (cells/mL)	5000	5000	5000	7000	12000	40000	33000	14000
Bluegill	189	163	152	123	114	109	0	0
Bluegreen Algae (cells/mL)	800	900	1300	1600	1000	500	400	400
Green Algae (cells/mL)	1000	2000	5500	7000	4000	1500	1000	2000
Heron	2	2	2	2	2	2	5	7
Bass	38	37	35	35	33	32	0	0
Minnows	356	320	299	278	250	237	233	446

Time Graphs

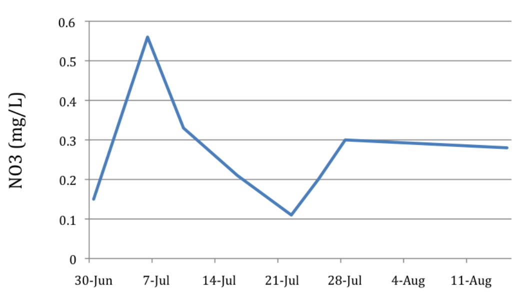
Phosphates (PO_4)

The housing development uses fertilizer that contains phosphates (PO4). When it rains, the fertilizer is washed into the pond, elevating the level of phosphate in the pond (July 6). The algae in the pond take up the phosphate, which lowers the level of phosphates in the water. On July 16th the concentration of phosphate in the pond reaches 0. This means the algae and bluegreen bacteria have used up all of the phosphate. When there is no phosphate left, the phytoplankton populations can no longer grow. Many of the phytoplankton die and sink to the bottom of the pond. Then organisms that eat dead plant materials (scuds and insect larvae) along with bacteria decompose the dead algae. In the process of decomposition, organic material is broken apart and phosphates that were bound in organic material are released into the water. Thus, the process of decomposition allows phosphates to once again be available for phytoplankton growth and reproduction.



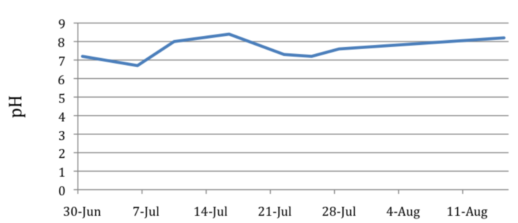
Nitrates (NO3)

The housing development uses fertilizer containing nitrates. When it rains on July 6, this washes the fertilizer into the pond, elevating the levels of nitrates in the pond. The algae in the pond take up the nitrate, which lowers the levels of nitrate in the water. The process of decomposition and release of nitrogen is similar to that described for phosphates above.

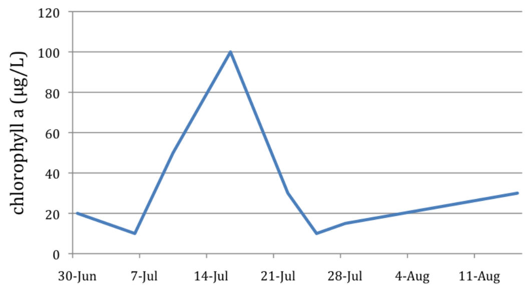


pH

The pH in the pond remains relatively constant over the period in which students visit.

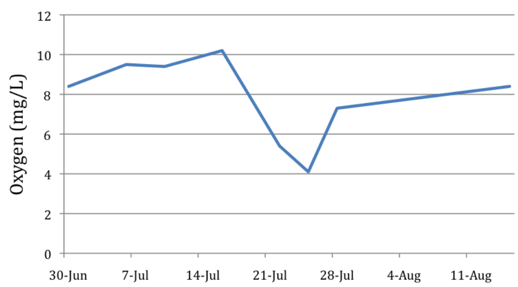


Chlorophyll a (ug/L)



When the levels of phosphate and nitrate of green algae and bluegreen algae increase because the algae absorb the phosphate and nitrate and use it. Because chlorophyll a is a chemical contained in algae cells, when the algae population increases, the concentration of chlorophyll a increases as well. This makes chlorophyll a a good indicator of the number of algae in the population. When the number of algae increases, the algae use up the nutrients (phosphate and nitrate) and phosphate becomes a limiting nutrient. When phosphate becomes limiting, the population of algae decreases until more phosphate is released during decomposition.

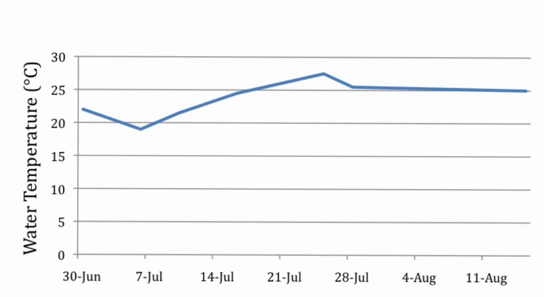
Oxygen (mg/L)



As the level of algae increases, the amount of oxygen will increase as well because algae give off oxygen through photosynthesis. When algae die and sink to the bottom of the pond, they are decomposed by bacteria. Bacteria use oxygen during the process of decomposition (via respiration) and thus the level of oxygen in the pond decreases as well. The oxygen declines for a number of reasons. In addition to much of the oxygen being used by bacteria, oxygen is no longer being replenished by phytoplankton during photosynthesis. Also, the weather has become warm and warm water cannot hold as much oxygen as cold water. On top of all this, there is little wind during the period around July 25th. Oxygen could be mixed into the pond when the wind blows, but this source of oxygen is absent on July 25th. All of these causes contribute to the low concentration of dissolved oxygen that is observed on July 25th. The students visit the pond each day at 3pm – this is a time when photosynthesis (and thus oxygen production) should be at its peak. This means the peak in daily oxygen concentration is represented in this plot. If students were to visit at night, they would see that each night the oxygen levels in the pond get quite low (4-6 mg/L) because oxygen is being used by all organisms through respiration, but is not being replenished by photosynthesis. If students visited on the night of July 25th they would see that oxygen concentrations are below 2mg/L for much of the night. These low concentrations are enough to kill the bass and bluegill, which need more dissolved oxygen than minnows.

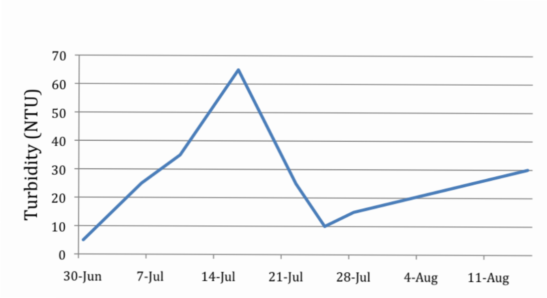
Water Temperature (ºC)

The water temperature remains relatively constant. The temperatures happen to be at their peak on July 25th. This contributes to the low oxygen concentrations because warm water cannot hold as much oxygen as cold water.



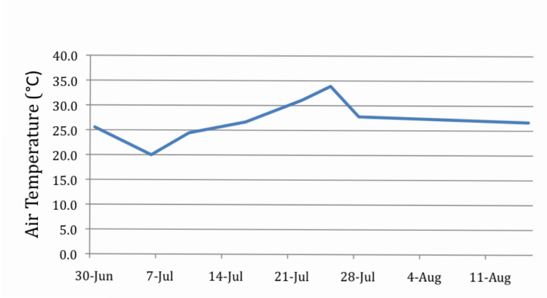
Turbidity (NTU)

Turbidity is a measure of the cloudiness of the water. Turbidity may be high when there are a lot of sediments suspended in the water or when there are a lot of microscopic plants (green algae and bluegreen algae) floating in the water. The turbidity is high after the rain because sediments are washed into the pond with the rain. The wind associated with the storm also causes waves and mixing in the pond can stir up the sediments on the bottom of the pond. Turbidity remains high between July 6 and July 16th because the algae populations grow and make the water green and murky.



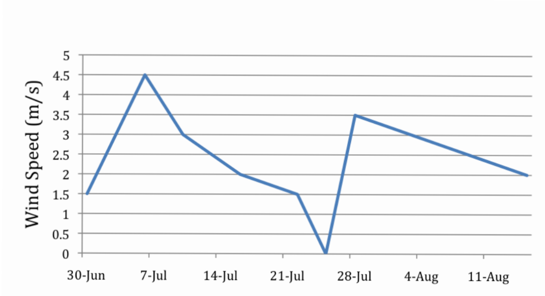
Air Temperature (ºC)

The air temperature shows a similar trend to that of water temperature.



Wind Speed (m/s)

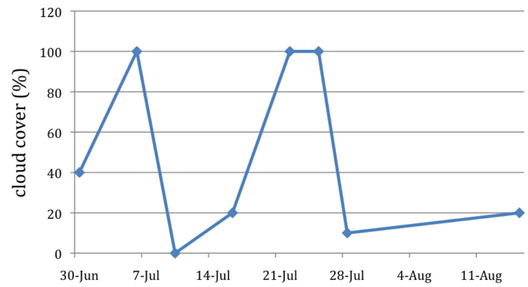
The wind speed observed at the pond is high on July 6th when there are high wind speeds associated with the rain storm. Wind speed is notably low on July 25th. This contributes to the fish kill be-



cause mixing caused by the wind can replenish oxygen in the pond. However, this does not happen on July 25th.

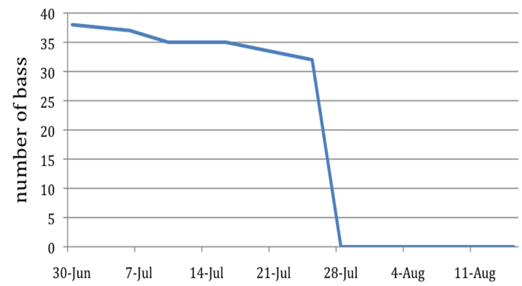
Cloud Cover (%)

Cloud cover is high on July 6, and also on July 22 and July 25th. The cloudiness contributes to the fish kill because with less sunlight there is less photosynthesis, and thus less opportunity for the oxygen in the pond to be replenished.



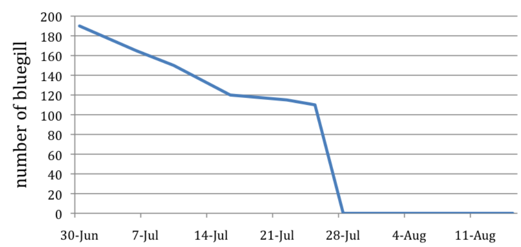
Largemouth Bass Population

The number of largemouth bass in the pond slowly decreases over time due to natural mortality, such as a hawk or a fisherman leaving with one of the bass. Larger fish such as bass need oxygen to survive. When the dissolved oxygen declines below 2 mg/L, the bass die.



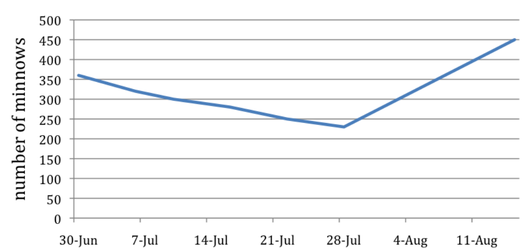
Bluegill Population

The number of bluegill in the pond slowly decreases during the early part of the summer because a number of bluegill are eaten by largemouth bass. Bluegill need oxygen to survive, and when the dissolved oxygen decreases the bluegill die.



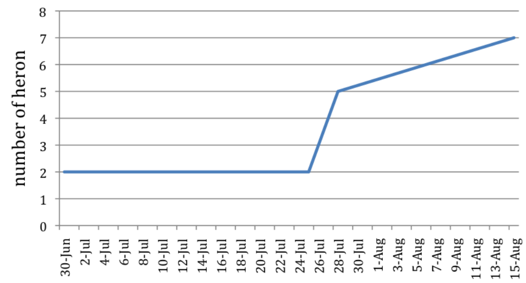
Minnow Population

During the early part of the summer the minnow population slowly declines because minnows may be eaten by largemouth bass, bluegill, and herons. When the larger fish die, the minnow population increases because they have very few predators.



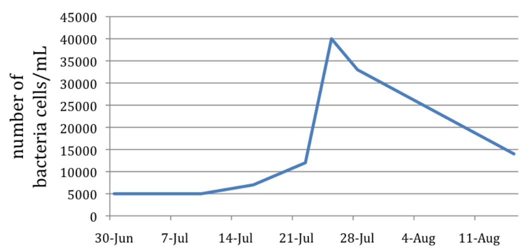
Heron Population

Before the large fish die, the heron population is fairly constant. When the large fish die, the heron population increases because it has a ready food supply in the dead fish. The heron population remains high because there are more minnows in the pond that continue to provide a source of food for the herons.



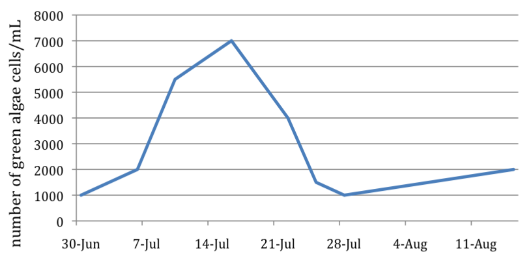
Bacteria Population

When the algae die due to nutrient limitation, they provide an increased food supply for bacteria, so the bacteria population increases. Then, when the majority of the dead algae have been consumed by the bacteria, the bacteria in the pond decreases.



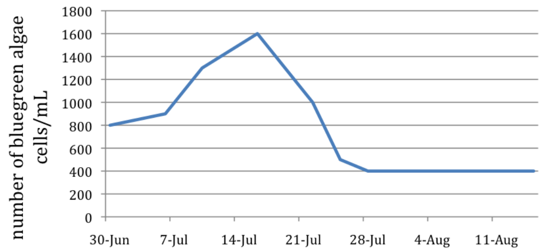
Green Algae Population

When the rain falls on the fertilizer used by the housing development, phosphorous and nitrogen are washed into the pond. When the levels of phosphorous and nitrogen in the pond increase, the amount of algae increases because the algae absorb the phosphorous and nitrogen and use it. When the number of algae increases, the algae use up the nutrients (phosphate and nitrate) and phosphate becomes a limiting nutrient. When phosphate becomes limiting, the population of algae decreases until more phosphate is released by bacteria during decomposition.



Bluegreen Algae

The pattern for bluegreen algae is similar to that of green algae.



Calendar of Events

Character Interactions and Atom Tracker

This appendix contains a detailed account of the non-player characters, objects, and atoms that the students may encounter on each virtual day they visit the pond.

June 30

Characters and Objects	Location	Information
Landscaper	Near land-scaping truck.	"Hi, I'm Manny. We've been working really hard to get the new housing development ready for the open house. I'm probably going to have to work overtime every day this week to get these lawns in shape! I think this extra fertilizer I picked up should do the trick."
Park ranger	Near the kiosk.	"Hi! Welcome to Scheele Pond! I'm Ranger Susan. I lead nature hikes near the pond and I keep an eye on changes in the pond. I could use your help! Check back with me when you visit again and I will have new information for you."
Landscaping truck	Near the road that leads to the housing development.	There are 3-4 fertilizer bags on the back of the landscaping truck and 1 bag on the side of the truck, which is open and being used by the landscaper.

Atoms	Location	Information
Carbon	In duckweed patch near edge of pond, near the ducks.	"Hi, I'm a carbon atom! I've been a part of a starch molecule in this duckweed plant for a while. Whoa! My duckweed plant just got eaten by a duck! Now I'm in the duck's stomach."
Oxygen	In the soil at the base of one of the trees.	"Hi, I'm an OXYGEN atom! I'm part of a water molecule. I landed as a raindrop a couple of days ago, and I've been hanging out in the soil. I've sunk deeper and deeper into the soil each day. Now I'm getting close to tree roots."

Phosphorus	Near the base of one of the maple trees.	"Hi! I'm a PHOSPHORUS atom! I'm trapped in a maple seed. I'm part of a complex fat molecule. A squirrel buried the maple seed here last fall. The conditions aren't right for the seed to grow here, so I guess I'll just stay here until the seed decomposes… This could take a while."

July 6

Characters and Objects

None.

Atoms	Location	Information
Carbon	Bottom of the pond underneath the ducks.	"The duckweed really got ripped apart in the ducks' stomach. But my starch molecule made it through the digestion process. The duck sent me into the water in its poop! I've settled down to the bottom of the pond. It's amazing that I'm still a part of the same starch molecule!"
Oxygen	Up in the same tree as the June 30 location.	"Once I got close to those tree roots in the soil I got taken into the roots. Then from the roots of the tree I traveled all the way up to one of the leaves. The trip didn't even take very long!"
Phosphorus	Near the squirrel.	"Whoa! The squirrel just found the seed I'm part of! And she was hungry, too, so I got into the squirrel's stomach and was digested. Now I'm part of a phosphate molecule, and I got swept into the bloodstream! Looks like I'll stay here for a while."

July 10

Characters and Objects	Location	Information
Young girl	Among the trees along the shore of the pond.	"Have you seen my dog? His name is Jasper. He ran away when I opened the door. I'm afraid he might be lost because we just moved into a new house across the street. I hope he remembers how to get home! I want to find him before he goes swimming in the pond. The water looks kind of gross today. It didn't look this green when I moved in last week."

Golfer	In the middle of the golf course area.	"Hi there. It's great to be out on the links again after all that rain."
Birdwatcher	On the hill.	"Hi, I'm Maria. I like watching birds near the pond. I just learned from Ranger Susan that populations of organisms need certain amounts of resources. If individuals in the population get more resources, the population can grow. But, if individuals don't get enough resources, some individuals die and the population decreases. I'm looking forward to seeing how the populations of organisms around the pond change over the summer!"

Atoms	Location	Information
Carbon	Bottom of the pond, under-neath the ducks. (Same as the July 6 location.)	"Oh boy – here comes some bacteria. There are a lot of them down here! Bacteria are good at getting energy out of other organisms' waste. They can get their energy from dead organisms. They break apart molecules that were once inside dead plants and animals. They release atoms and molecules so they can be used again. This is called DECOMPOSITION."
Oxygen	In the air near the tree where it was previ-ously found.	"Once I was in the leaf the plant used my water molecule to do PHOTOSYNTHESIS. During PHOTO-SYNTHESIS the plant used carbon dioxide from the air and my water molecule to make a sugar mol-ecule called glucose. The water molecule that I was a part of was broken apart and I was put into the air as an oxygen molecule."
Phosphorus	Near the squir-rel. (Same at the July 6 loca-tion.)	"Wow! We've been doing a lot of work in the squirrel's bloodstream! I'm a really important atom that is used in a lot of ways. But, I just entered the kidney and got news that there's more phosphate in the bloodstream than the squirrel needs! My phosphate molecule is going to be excreted in the squirrel's urine. Eww!"

July 16

Characters and Objects	Location	Information
Landscaper	Near the shore of the pond.	"I love doing yoga by the pond. The breeze helps me focus my chi. But man, this pond seriously reeks today. It smells like sewage! I reported it to the city so they can send someone to check on whether there was a leak. Look for a construction worker near the houses."
Golf course groundskee-per	Near the golf course.	"Hi, I'm Mr. Mulligan. Best part of my job – free golf any time I want! But with the new housing devel-opment down the street, I don't have as much free time as I used to! Business has really picked up!"
Construction worker and public works truck	On the road near the drain-age pipe and housing devel-opment	"Hi, I'm Ms. Vasquez. Someone reported a pos-sible leak in the sewage line, but these sewage pipes look just as good as the day we put them in. Thank goodness there was never any sewage leaking into the pond."
Park ranger	Near the shore of the pond.	"Even tiny floating plants, like algae, need certain levels of nutrients like phosphates and nitrates. If they don't get enough nutrients they can die. How can you tell if the plants in the pond have enough nutrients? Try out some of the measure-ment tools to find out!"

Atoms	Location	Information
Carbon	In the wa-ter near the ducks. (Sign is visible under the water.)	"The bacteria broke my starch molecule to re-lease energy that their cell could use. The bac-teria had to take in OXYGEN to break down my starch molecule for energy. What was that pro-cess called again? Oh yeah – RESPIRATION. Now, I was released back into the water as carbon dioxide. Bacteria break down material into smaller molecules that are released back into the envi-ronment. That's why we call them DECOMPOS-ERS."
Oxygen	In the atmo-sphere directly above the pond.	"I've been floating around in the atmosphere for a while. Whoa! Here comes a big wind! The wind just mixed me into the water in the pond! I guess that makes me DISSOLVED OXYGEN!"

Phosphorus	In the soil undernear the squirrel.	"Well, I made it out of the squirrel and am hanging out here in the soil. I'm still part of a phosphate molecule."

July 22

Characters and Objects	Location	Information
Construction worker	Near the public works truck on the side of the main road.	"Hi, I'm Ms. Vasquez. Someone reported a leak in the sewage line. Four hours, three coffees, two donuts and one golf ball to the head later and these sewage pipes look just as good as the day we put them in.
Park ranger	Near the kiosk.	" E. Coli levels in the pond are high today. E. Coli is a kind of bacteria that makes people sick. But not all bacteria are bad. Bacteria are important in ecosystems. They can be producers or decomposers. You can read more about them in your Field Guide!"

Atoms	Location	Information
Carbon	Floating in the pond.	"Wheee! Now that I'm back in the carbon dioxide molecule I could be taken up by a plant at any moment to be used in PHOTOSYNTHESIS, but for now I'm free! I'm a gas molecule, but I'm surrounded by water – it's a pretty strange feeling."
Oxygen	Floating in the pond near the edge, where there may be a bass.	"Mmmm… Floating in the pond has been kind of relaxing. Oh – here comes a big bass. I just went right through his mouth and got stuck on his gills! From the gills I am being carried through the bloodstream to one of the fish's cells. I wonder what will happen there?"
Phosphorus	Floating in the pond.	"It rained so hard yesterday that we got swept along with the flow of the water. We all got swept right into the pond! I didn't stay in the water very long, though. All the algae really needed phosphorus. I was taken up right away by a green algae!"

July 25

Characters and Objects	Location	Information
Young girl	In a yard near the houses.	"Hi again! I really like this new neighborhood. Ranger Susan taught me how to take different water samples like dissolved oxygen, pH, phosphates and turbidity. Have you tried the water measurement tools?"
Golf course groundskeeper.	Near the blue golf course maintenance shed.	"I am trying to take care of fertilizing the golf course like I do every week, but I can't seem to find my glasses. Must have left them at the clubhouse. Can you help me read the instructions on this fertilizer bag? Thanks! I'm always really careful to follow those instructions. We don't want to waste any fertilizer. This stuff can get expensive when you have to fertilize a whole golf course."
Park ranger	On the hill.	"Decomposers play a really important role in ecosystems. They break down dead organisms so the nutrients in the dead organisms can be used again. They are the ultimate recyclers! Who are the major decomposers in the pond?"
Fertilizer bags	Outside the maintenance shed.	A whole stack of bags is piled outside the maintenance shed. When the students talk to the golf course groundskeeper, he will ask them to click on the fertilizer bag to read the label. When clicked on, the label reads, "Professional Turf Fertilizer (40 lbs.) Contains nitrogen, phosphorus and potassium – nutrients essential for plant growth. Apply 1 pound for every 1,000 square feet of turf. Apply only as directed. Avoid applying before it rains to prevent loss of nutrients before they are taken up by plants."

Atoms	Location	Information
Carbon	Floating in the pond.	"I bumped into a green algae cell and it absorbed me right through its cell wall! The green algae used a process called PHOTOSYNTHESIS to turn a bunch of my carbon dioxide buddies and me into a glucose molecule."

Oxygen	In a fish on the edge of the pond.	"While in the fish's cell I got to help with RESPIRATION! I helped the fish cell break apart glucose molecules and the fish's cell got a burst of energy. The fish needs a lot of OXYGEN to make this happen. After I helped with RESPIRATION, I picked up a CARBON atom, and now I'm part of carbon dioxide in the fish's bloodstream. Once we make it to the gills we'll be back in the water again. Fish always give off carbon dioxide after respiration, just like humans!"
Phosphorus	Floating in the pond.	"I've been helping with PHOTOSYNTHESIS. Because PHOSPHORUS is so important to plants, they can't grow well if they don't have enough. I've had to work hard during the day, but then I've had the nights off. We could only do PHOTOSYNTHESIS during the day when there was sunlight. RESPIRATION just keeps happening, whether it's day or night."

July 28

Characters and Objects	Location	Information
Park ranger	On the shore of the pond.	"Did you see all of the dead fish? We're trying to figure out what happened. I'm going to take a few fish to the lab to see if they were killed by a virus called viral hemorrhagic septicemia (VHS). You should look around the pond for any other possible causes. What's been changing around here lately? Check back with me in a couple weeks to find out the results of the lab tests."
Birdwatcher	On the hill.	"This is pretty cool. The herons are eating all of the dead fish. I wonder if their population will change because they have more resources."

Atoms	Location	Information
Carbon	Floating in the pond.	"The green algae linked me with a bunch of other glucose molecules to make a big molecule called starch. Did you know that starch is the same kind of molecule that you find in potatoes? And duckweed!"

Oxgyen.	Near the edge of the pond, near an elodea plant.	"My carbon dioxide molecule got absorbed by the leaf of the elodea plant! I get to help make glucose molecules instead of breaking them apart. Using PHOTOSYNTHESIS, the plant just linked us with a bunch of other carbon dioxide molecules to make a glucose molecule. Glucose is a simple sugar that can provide energy for the plant. But it looks like the plant has enough energy right now, so we're getting linked with a bunch of other glucose molecules to make a starch. Starch is the perfect way for this plant to store a bunch of glucose molecules (and the energy they contain) for later."
Phosphorus	In the pond.	"The algae cell that I was a part of just got eaten by a Daphnia! The Daphnia digested the algal cell and broke apart the glucose and starch molecules for energy. During RESPIRATION the Daphnia has been using up a lot of OXYGEN and giving off a lot of carbon dioxide molecules. My molecule was ripped apart and now I've been put back into the water as a phosphate molecule."

Aug 15

Characters and Objects	Location	Information
Golfer	On a lawn near the housing development that leads to the drainage ditch.	"I paid that guy Manny to look after my lawn, but I haven't seen him in weeks. I've been taking care of it myself. If you see him around, tell him not to bother coming back. Hmmm… I think one bag should be about right for my lawn."
Park ranger	Near the kiosk.	"Hi there! I just got the lab results back this morning. We found out that the fish that died did not have viral hemorrhagic septicemia (VHS). There must have been something else that caused their death. Do you have any ideas about what could have caused it?"

Fertilizer bags	In the back-yard of the golfer's house. (The golfer's house is the one that leads directly to the drainage ditch.)	There are two bags. One bag is almost full and the other one is empty.

Atoms	Location	Information
Carbon	In the pond near the edge where you might encounter a fathead minnow.	"Wow! The algae cell that I was a part of just got eaten by a fathead minnow! The minnow broke apart most of the glucose and starch molecules in the algae for energy. During RESPIRATION the minnow used a lot of OXYGEN and gave off a lot of carbon dioxide molecules. My starch molecule was ripped apart and now I'm back in the water as a carbon dioxide molecule."
Oxygen	Floating in the pond near the elodea plants.	"Did you know that plants do RESPIRATION? I got to see it happen last night! Just like animals, plants use the process of RESPIRATION to gain energy from starch and glucose molecules. So, last night the plant took in a bunch of oxygen and used it during RESPIRATION to break down the starch molecule that I was a part of. When the starch molecule got broken apart, I was released from the plant as a part of a carbon dioxide molecule."
Phosphorus	Floating in the pond.	"I've been dissolved as phosphate in the water for a while. The algae haven't been as hungry for phosphate. I guess when there are plenty of phosphate molecules in the water they are not as ready to absorb us and use us to grow. In fact, there don't seem to be as many algae around as there were."

Glossary

Terms and Concepts

Abiotic: non-living.
See also: Biotic

Acid: a substance with a pH less than 7. Acids tend to be sour and corrosive. When an acid combines with a base, it neutralizes it. Some examples of acids are stomach acids, lemon juice, vinegar, and soda. A substance can be acidic, neutral, or basic.
See also: pH, Base, Neutral, Chemical

Algae: single-celled or multicellular organisms that live in water and make food through photosynthesis. They can be as small as a single cell or as large as giant seaweed. They are similar to plants, but are not considered plants because they do not have roots, stems, or leaves.
See also: Photosynthesis, Phytoplankton, Plankton, Zooplankton

Algal bloom: a large increase of the algae population, sometimes because of pollutants that increase nutrients in the water. Nutrients are food for algae, and water with a lot of nutrients can produce a lot of algae.
See also: Pollutant, Nutrient, Nitrate, Phosphate, Fertilizer, Algae, Scum, Eutrophication

Analyze: to study something by breaking it down into simpler parts.
See also: Classify

Aquatic: living in water.

Bacteria: single-celled organisms. Many are microscopic.
See also: Microscopic

Balance: balance is a state of equilibrium, where different forces cancel each other out. Ecosystems involve both balance and flux.
See also: Flux

Base: a substance with a pH greater than 7. Also called "basic." When a base is combined with an acid, it neutralizes it. Some examples of bases are detergent, soap, and baking soda. A substance can be acidic, neutral, or basic.
See also: pH, Acid, Neutral

Biology: the study of living things
See also: Biological, Biotic

Biotic: living.
See also: Abiotic

Causality: the relation between cause and effect:
- Causes can have direct and indirect effects.
- Causes can have far-reaching effects.

- A seemingly small cause can have extensive effects.
- In a system, isolated effects are uncommon.
- Effects often appear to happen in domino-like patterns: one causes another, which causes another, and so on.
  See also: Effect, Complex causality, Cyclic causality, Domino causality, Two-way causality

Chemical: a substance that appears the same throughout its structure. For example, water and lemon juice are chemicals, but a puppy is not.
See also: Chemistry

Chemistry: the study of matter and its interactions with other matter. Matter is anything that takes up space, alive or not.
See also: Biology, Chemical

Classify: to group things together because they share one or more properties.
See also: Analyze

Conclusion: a decision that is based on observation or on a study of data.
See also: Data, Experiment, Controlled Experiment

Consumer: an organism that feeds on other organisms or organic matter because it cannot make its own food.
See also: Predator, Detrivore, Decomposer, Food web, Organism

Cyclic Causality: in a cyclic pattern, a cause causes an effect that in turn has an effect on the initial cause. For instance, in ecosystems, plants grow and then die. Decomposers decay them and release nutrients within the plant back into the soil, which affects the growth of other plants.
See also: Nutrients, Causality, Complex causality

Data: information, such as that gathered during an experiment.
See also: Experiment, Evidence

Decay: the breakdown of dead organic material by decomposers.
See also: Decomposer, Detrivore, Bacteria

Decomposer: an organism that eats dead organic matter. Most are bacteria, algae, and fungi.
See also: Decay, Detrivore, Bacteria, Algae, Organic, Organism

Dissolved Oxygen: dissolved oxygen (DO) is found in microscopic bubbles of oxygen that are mixed in the water and occur between water molecules. DO is a very important indicator of a water body's ability to support aquatic life. Fish "breathe" by absorbing dissolved oxygen through their gills. Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algae photosynthesis. Oxygen is removed from the water by respiration and decomposition of organic matter.
See also: Aquatic, Photosynthesis, Algae, Respiration, Decomposition

Domino Causality: effects often appear to happen in domino-like patterns: one causes another, which causes another, and so on. Domino causality is important for understanding the process of energy flow in food webs, and the important link from the sun to green plants as the source of that energy. It offers a means to think about the far reach of certain events within an ecosystem.
See also: Causality, Complex Causality

Dynamic: continuously changing.
See also: Flux

Ecological: having to do with the relationship between organisms and their environments.
See also: Organism, Environment, Ecology, Ecosystem

Ecology: the science concerned with the relationships among living things and their environment.
See also: Organism, Environment, Ecological, Ecosystem

Ecosystem: a community that includes all the living and nonliving things found in a certain area.
See also: Organism, Abiotic, Environment, Ecology, Ecological

Effect: result.
- Causes can have direct and indirect effects.
- Causes can have far-reaching effects.
- A seemingly small cause can have extensive effects.
- In a system, isolated effects are uncommon.
- Effects often appear to happen in domino-like patterns: one causes another, which causes another, and so on.

See also: Causality, Complex Causality

Energy: living things obtain energy from the sun. That energy then moves through the environment through the food web.
See also: Food web, Photosynthesis, Feeding relationship, Predator, Prey

Environment: everything that surrounds an organism and influences it.
See also: Organism, Ecosystem

Eutrophication: nutrients are food for algae and water. High amounts of nutrients can produce algae in large quantities. When these algae die, bacteria decompose them, and use up oxygen. This process is called eutrophication. Oxygen concentrations can drop too low for fish to breathe, leading to fish kills. However, nutrients can also lead to increased plant growth. This can lead to high dissolved oxygen [DO] concentrations during the day as photosynthesis occurs, and low DO concentrations during the night when photosynthesis stops and plants and animals use the oxygen during respiration. Nitrate and phosphate are nutrients. Nitrate is found in sewage discharge, fertilizer runoff, and leakage from septic systems. Phosphate is found in fertilizer and some detergents.
See also: Run-off, Watershed, Algae, Dissolved oxygen, Respiration, Photosynthesis, Nitrate, Phosphate, Phytoplankton

Evidence: something that offers proof.
See also: Data

Experiment: a procedure that is carried out to investigate a scientific question.
See also: Data, Controlled experiment, Evidence

Fertilizer: any natural or man-made substance that is added to soil to help plants grow.
See also: Nutrients, Nitrate, Phosphate, Watershed

Fluctuation: changes over time.
See also: Flux

Flux: change. Ecosystems involve both balance and flux. Typically, studies of ecosystems stress balance. Indeed there is a great deal of redundancy and ability to adapt in ecosystems that provides balance. However, ecosystems typically include some fluctuations as well. Flux is not necessarily negative; it can create patterns in an ecosystem that are ultimately healthy. For instance, it can allow for new species to become established.

See also: Balance, Ecosystem

Food web: all the interactions of predator and prey, along with the exchange of nutrients into and out of the soil. These interactions connect the various members of an ecosystem, and describe how energy passes from one organism to another. Food web diagrams emphasize the circular complexity of feeding relationships.

See also: Predator, Prey, Energy

Habitat: a place that is natural for an organism to live.

See also: Ecosystem, Environment, Organism

Hypothesis: a prediction about how something works or how two variables are related.

See also: Experiment, Controlled experiment, Data, Evidence

Indirect effect: ecosystems are characterized by connectedness, and in ecosystems, causes often have many indirect effects. An indirect effect is an effect that is seemingly unrelated to any recent cause.

See also: Causality, Complex causality

Inorganic: not from living things; minerals, water, oxygen, etc.

See also: Abiotic

Larva (plural, larvae): a stage in the life cycle of some organisms. A caterpillar is a larva.

Limiting factor: the growth of an organism or population depends on there being enough of what it needs. The limiting factor of growth is the point when there is no more of that resource, and so the organism or population cannot grow any further.

See also: Organism, Population, Habitat

Measurement: a way of judging something's size or amount.

Microbe: a microscopic organism, especially one that causes disease.

See also: Bacteria, Organism, Microscopic

Microscopic: something that is so small that it cannot be seen by human eyes; you need a microscope to see it.

Monitoring: periodic or continuous surveillance, watching, or testing.

Native species: a species that occurs naturally in an area, and has not been introduced by humans either intentionally or unintentionally.

See also: Non-Native, Species, Invasive, Invasion

Neutral: a substance with a pH of 7, halfway between acidic and basic.

See also: Acid, Base, pH

Nitrogen: nitrogen is required by all organisms for the basic processes of life to make proteins, to grow, and to reproduce. Nitrogen is very common and found in many forms in the environment. Inorganic forms include nitrate (NO_3) , nitrite (NO_2) , ammonia (NH_3), and nitrogen gas (N_2). Organic nitrogen is found in the cells of all living things and is a component of proteins, peptides, and amino acids. Excessive concentrations of nitrate, nitrite, or ammonia can be harmful to humans and wildlife. This process is called

eutrophication. Nitrate, nitrite, and ammonia enter waterways from lawn fertilizer run-off, leaking septic tanks, animal wastes, industrial waste waters, sanitary landfills and discharges from car exhausts.
See also: Eutrophication, Run-off, Fertilizer, Watershed

Non-native species: a species whose presence is due to intentional or unintentional introduction as a result of human activity.
See also: Native, Species, Invasive, Invasion

Non-obvious cause: hard to detect with the naked eye. Non-obvious causes can make it difficult to recognize that certain causal patterns exist. For instance, recognizing the cyclic model in decay involves recognizing tiny microbes as the primary decomposers. It also involves dealing with the time delay in nutrient recycling.
See also: Causality, Complex causality

Non-point source (NPS) pollution: non-point source pollution is contamination that occurs when rainwater, snowmelt, or irrigation washes off plowed fields, city streets, or suburban backyards. As this runoff moves across the land surface, it picks up soil particles and pollutants, such as nutrients and pesticides.
See also: Soil, Run-off, Watershed, Nutrient, Pollutant

Nutrient: any element or simple compound necessary for the health and survival of an organism. This includes air, water, and food.
See also: Organism

Opinion: an expression of how one thinks or feels about something. An opinion is based on personal views, not necessarily on facts.
See also: Data, Evidence

Organic: refers to living things or the materials made by living things.
See also: Biotic

Organism: any living thing that has living characteristics and is composed of one or more cells.

pH: (Potential Hydrogen) a scale to measure the alkalinity or acidity of a substance. The scale ranges from 0 to 14. Substances with a pH below 7.0 are acidic, and those above 7.0 are alkaline, with 7.0 neutral. Acids tend to be sour and corrosives, and bases (alkaline compounds) the opposite, and slippery. Natural waters usually have a pH between 6 and 9. The pH of a pond may vary depending on the time of day.
See also: Acid, Base, Neutral

Parameters: the limits or boundaries of a system. Parameters of the pH scale are 0 and 14.

Pattern: a repeating arrangement of shapes, colors, numbers, or other things.

Phosphorus: a nutrient required by all organisms for the basic processes of life. Phosphorus is a natural element found in rocks, soils and organic material. Its concentrations in clean waters is generally very low; however, phosphorus is used extensively in fertilizer and other chemicals, so it can be found in higher concentrations in areas of human activity. Phosphorus is generally found as phosphate. High levels of phosphate, along with nitrate, can over stimulate the growth of aquatic plants and algae, resulting in high dissolved oxygen consumption, causing death of fish and other aquatic organisms. The primary sources of phosphates to surface water are detergents, fertilizers, and natural

mineral deposits.
See also: Nutrient, Organism, Fertilizer, Algae, Algal bloom, Dissolved oxygen, Aquatic

Photosynthesis: the process by which green plants and blue-green algae, in the presence of light, make food out of carbon dioxide and water.
See also: Phytoplankton, Algae, Energy, Food web, Producers

Phytoplankton: that portion of the plankton community comprised of tiny plants; algae, diatoms, etc.
See also: Algae, Photosynthesis

Plankton: microscopic algae and protozoa drifting in water. Larger organisms graze them like grass.
See also: Algae, Microscopic

Pollutant: anything that spreads harmful or unpleasant substances into the air, water, or ground.
See also: Contaminant, Contamination

Population: a group of potentially inter-breeding individuals of the same species found in the same place at the same time.
See also: Species

Predator: organism which hunts and eats other organisms. This includes both carnivores, which eat animals, and herbivores, which eat plants.
See also: Organism, Consumer, Food web, Energy

Prey: organism hunted and eaten by a predator.
See also: Organism, Food Web, Energy

Producer: an organism that can make its own food through the process of photosynthesis.
See also: Photosynthesis, Organism, Food web, Energy

Respiration: the processes by which an organism takes in and processes oxygen and releases carbon dioxide.
See also: Organism

Run-Off: the part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface-water. It can carry pollutants from the air and land into receiving waters.
See also: Non-Point source pollution, Watershed, Pollutant

Sample: a small but representative part of a greater whole

Scavenger: an organism that eats dead or decaying organic matter. Scavengers are also known as decomposers.
See also: Organism, Decomposer, Detrivore

Sediment: small pieces of rock, plant, and animal material that are carried by water, wind, or ice.

Sewer: a channel or conduit that carries wastewater and storm-water runoff from the source to a treatment plant or receiving stream. "Sanitary" sewers carry household, industrial, and commercial waste. "Storm" sewers carry runoff from rain or snow. "Combined" sewers handle both.

See also: Run-off, Storm drain, Watershed

Silt: very tiny particles of soil or rocks.
See also: Sediment, Siltation

Soil: dirt that is enriched with nutrients from decayed organisms. Soil is rich enough to support the growth of new plants.
See also: Detritus, Organism

Species: a group of organisms that can reproduce with each other.
See also: Population, Organism

Stable: steady, balanced.
See also: Balance

Steady-state monitoring: see *monitoring.*

Storm drain: a system of gutters, pipes, or ditches used to carry stormwater runoff into sewers or streams.

System: a number of objects or units that move or work together as a whole.

Temperature: temperature of water is a very important factor for aquatic life. It controls the rate of metabolic and reproductive activities. Most aquatic organisms are "cold-blooded," which means they can not control their own body temperatures. Their body temperatures become the temperature of the water around them. Cold-blooded organisms are adapted to a specific temperature range. If water temperatures vary too much, metabolic activities can malfunction. Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria in a water body.
See also: Aquatic, Organism, Dissolved oxygen, Bacteria

Terrestrial: of or related to the land.

Thorax: the middle segment of an insect.

Time delay: there are often significant time delays between causes and effects in ecosystems. This can make it difficult to trace an effect back to its cause, or even to see the pattern of causality involved. For example, time delays make it harder to recognize indirect, extended effects in domino patterns. It is common for natural systems to have checks and balances that dampen effects, slowing the appearance of obvious effects. For instance, the environment may be able to absorb a certain amount of pollution before any obvious effects appear, but eventually there will be enough accumulation that the effects become dramatic.
See also: Causality, Complex causality

Turbidity: a measure of the cloudiness of water - the cloudier the water, the greater the turbidity. Turbidity in water is caused by suspended matter such as clay, silt, and organic matter and by plankton and other microscopic organisms that interfere with the passage of light through the water. High turbidity can be caused by soil erosion, urban runoff, and high flow rates.
See also: Silt, Plankton, Organism, Microscopic, Erosion, Run-off

Two-way causality: in a two-way pattern, one event or relationship has mutual, and often simultaneous, effects. Each component has an effect on the other, so each acts as both an effect and a cause. For instance, two-way causality can be seen in symbiotic relationships where an event or action (such as a bee pollinating a flower) results in effects on both organisms (the bee and the flower). It differs from a cyclic model in that the focus is on how one event (a bee pollinating a flower) or relationship (a tick sucking blood from a dog) has mutual, and typically simultaneous, effects (bee gets nectar and flower gets pollinated or tick gets nourishment and dog is weakened). Some two-way relationships might also involve cyclic causality if viewed over the long-term relationship.

See also: Complex causality, Causality, Symbiosis

Variable: an element in an experiment that can be changed.

See also: Experiment, Controlled experiment

Water cycle: the process by which water (and some pollutants) move through the environment; evaporation, precipitation, etc.

Water pollution: condition that exists when harmful materials have entered the water and made it harmful to organisms.

See also: Pollution, Organism

Water quality: measured by looking at levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

See also: Pollutant

Watershed: an area of land that is drained by a stream or river and its branches.

See also: Non-Point source pollution, Pollution, Tributary, Run-off, Spring, Outlet, Drainage

Zooplankton: plankton that do not produce their own food, as phytoplankton do. In size they fall between phytoplankton and larger organisms like fish.

See also: Plankton, Algae