SYSTEMS

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This introductory systems lesson is adapted from the AAAS Project 2061 Lesson "Seeing the Cell as a System": http://www.project2061.org/publications/rsl/online/GUIDE/CH2/HLPSYS0.PDF

SYSTEMS

Overview: The overarching goal of *Earth as a System is Essential: Seasons and the Seas* (EaSiE) is to transform the traditional middle school study of terrestrial seasons and weather into an exploration of the dynamic interactions between Earth's land, water, atmosphere, and the living world. This is an introductory unit that builds a fundamental understanding of systems. Emphasis will be placed on how various components of a student's local region relate and respond to each other. "Systems thinking" will be used in subsequent lessons to develop a global perspective, considering the Earth as a system composed of interactions among the lithosphere (land), atmosphere (air), hydrosphere and cryosphere (water), and biosphere (living things).

The unit begins by considering the bicycle as a system, transitioning to thinking about other manufactured objects as systems, and culminating with a natural system in the student's 'backyard'. Future learning experiences that will refer back to this systems perspective include lessons about 1) local weather & climate, 2) the Gulf of Maine as part of our regional system, and 3) seasonal and climate change.

This lesson sets the stage for the big idea: Earth can be conceived as an interacting set of processes and structures composed of the atmosphere, lithosphere, hydrosphere, and biosphere.

Related Goals from *Benchmarks for Science Literacy* (1993):

- A system can include processes as well as things (Systems, Grades 6-8).
- Thinking about things as systems means looking for how every part relates to others. The output from one part of a system (which can include material, energy, or information) can become the input to other parts. Such feedback can serve to control what goes on in the system as a whole (Systems, Grades 6-8).
- Any system is usually connected to other systems, both internally and externally. Thus a system may be thought of as containing subsystems and as being a subsystem of a larger system. (Systems, Grades 6-8).
- The earth is mostly rock. Three-fourths of its surface is covered by a relatively thin layer of water and the entire planet is surrounded by a relatively thin blanket of air (The Earth, Grades 6-8).

Related Unifying Concepts from *National Science Education Standards* (1996):

- The natural world is too complex to comprehend all at once, so scientists define small portions to investigate.
- A system is an organized group of related objects or components that form a whole. Systems have boundaries, components, resources flow (input and output), and feedback.

- The purpose of studying systems is to develop the ability to think and analyze in terms of systems. This can help us keep track of substances such as matter, energy, or organisms.
- Systems thinking can develop an understanding of the regularities in systems, which builds to an understanding of the basic laws, theories, and models that explain the world.
- Prediction from a systems perspective involves using knowledge and understanding of order to identify and explain observations or changes in advance.

Related Goals from *K-12 Science Literacy New Hampshire Curriculum Framework* (2006):

- Understand that any system is usually connected to other systems, both internally and externally; thus a system may be thought of as containing subsystems and as being a subsystem of a larger system (S:SPS2:8:2.1).
- Analyze how the output of one part of a system, which can include materials, energy or information can become the input to other parts (S:SPS2:8:2.2).
- Realize that as the complexity of any system increases, gaining an understanding of it depends increasingly on summaries (such as averages and ranges) and on descriptions of typical examples of that system (S:SPS2:8:2.3).

Related Goals from *Maine Learning Results (2007)*:

- Students describe and apply principles of systems in human-made things, natural things, and processes (A1).
- Explain how individual parts working together in a system can do more than each part individually (A1a).
- Explain how the output of one part of a system, including waste products from manufacturing or organisms, can become the input of another part of a system (A1b).
- Describe how systems are nested and that systems may be thought of as containing subsystems (as well as being a subsystem of a larger system) and apply the understanding to analyze systems (A1c).

Related Goals from *Massachusetts Science and Technology/Engineering Curriculum Framework (2006)*:

- Students should recognize the interacting nature of earth's four major systems: the geosphere, hydrosphere, atmosphere, and biosphere (ESS).
- In grades 6-8, the emphasis changes from observation and description of individual organisms to the development of a more connected view of biological systems (LS).
- At the macroscopic level, students focus on the interactions that occur within ecosystems (LS).

This systems perspective provides a foundation for developing an understanding of the *Ocean Literacy Essential Principles and Fundamental Concepts* (2006):

- The Earth has one big ocean with many features.
- The ocean is a major influence on weather and climate.
- The ocean supports a great diversity of life and ecosystems.
- The ocean and humans are inextricably interconnected.

Related Research on Student Learning from *Benchmarks for Science Literacy* (1993):

- Students may believe that a system of objects must be doing something in order to be a system – or - that a system that loses a part of itself is still the same system.
- Students tend to explain changes by a cause producing a chain of effects, and not two systems interacting (e.g. when a container is heated, the source applies heat to the receptor, rather than two systems interacting, with one gaining energy and the other losing it).
- Students often interpret phenomena by noticing the qualities of separate objects rather than by seeing the interactions between the parts of the system (e.g. thinking that whether or not a substance burns is determined solely by the substance, and not a process involving the interaction of the burning substance and oxygen).
- Students have difficulties explaining systems as both a sequences of changes over time and as inputs and outputs.
- Students struggle with the idea that parts interact to produce wholes which have properties the individual parts do not. They may think that the properties of an object are the same as the bits that make it up, changes in macroscopic properties are the result of the same microscopic change, or that if properties change, it's because the pieces that cause that property have moved away or disappeared.

Teacher Background - from *Science for All Americans (1990): http://www.project2061.org/publications/sfaa/online/chap11.htm#2*

Any collection of things that have some influence on one another can be thought of as a system. The things can be almost anything, including objects, organisms, machines, processes, ideas, numbers, or organizations. Thinking of a collection of things as a system draws our attention to what needs to be included among the parts to make sense of it, to how its parts interact with one another, and to how the system as a whole relates to other systems. Thinking in terms of systems implies that each part is fully understandable only in relation to the rest of the system.

In defining a system—whether an ecosystem or a solar system, an educational or a monetary system, a physiological or a weather system—we must include enough parts so that their relationship to one another makes some kind of sense. And what makes sense depends on what our purpose is. For example, if we were interested in the energy flow in a forest ecosystem, we would have to include solar input and the decomposition of dead organisms; however, if we were interested only in predator/prey relationships, those could be ignored. If we were interested only in a very rough explanation of the earth's tides, we could neglect all other bodies in the universe except the earth and the moon; however, a more accurate account would require that we also consider the sun as part of the system.

Drawing the boundary of a system can make the difference between understanding and not understanding what is going on. The conservation of mass during burning, for instance, was not recognized for a long time because the gases produced were not included in the system whose weight was measured. And people believed that maggots could grow spontaneously from garbage until experiments were done in which egg-laying flies were excluded from the system.

Thinking of everything within some boundary as being a system suggests the need to look for certain kinds of influence and behavior. For example, we may consider a system's inputs and outputs. Air and fuel go into an engine; exhaust, heat, and mechanical work come out. And we look for what goes into and comes out of any part of the system—the outputs of some parts being inputs for others. For example, the fruit and oxygen that are outputs of plants in an ecosystem are inputs for some animals in the system; the carbon dioxide and droppings that are the output of animals may serve as inputs for the plants. Some portion of the output of a system may be included in the system's own input. Generally, such feedback serves as a control on what goes on in a system. Feedback can encourage more of what is already happening, discourage it, or modify it to make it something different. But feedback in a system is not always prompt. For example, if the deer population in a particular location increases in one year, the greater demand on the scarce winter food supply may result in an increased starvation rate the following year, thus reducing the deer population in that location.

Any part of a system may itself be considered as a system—a subsystem—with its own internal parts and interactions. A deer is both part of an ecosystem and also in itself a system of interacting organs and cells, each of which can also be considered a system. Similarly, any system is likely to be part of a larger system that it influences and that influences it.

Systems are not mutually exclusive. Systems may be so closely related that there is no way to draw boundaries that separate all parts of one from all parts of the other.

Essential Question: What makes something a "system"?

Knowledge:

1. Define a system in terms of parts that interact or influence each other.
2. Give examples of systems.
3. Recognize that systems contain subsystems, and can be part of larger systems.

Preparation

Prepare copies of student handouts:

The Bicycle as a System

Questions to Ask About Systems

Materials:

Bicycle

For each group of three or four students, familiar objects with interacting parts that can be considered a system: kitchen devices such as a can opener, hand mixer, peeler, cheese grater; school supplies such as a stapler, 3-hole punch, pencil sharpener, scissors; mechanical toys, flashlight.

Time Required

2-3 class periods.

Teaching the Lesson:

Elicit/Engage

1. Ask students to give examples of systems they have heard about (they may be familiar with the terms ecosystem, solar system, body systems such as digestive or circulatory, sound system, school system). Create a list on the board.
2. Ride a bicycle into the room. Ask, "Is this bicycle a system?" Have students justify responses, and use this to begin to develop a working definition of a system. This is a brief elicitation of prior knowledge; it is not necessary to go into great detail at this point. They may suggest that a system is made of parts, and the parts interact. If they don't, they will revisit this working definition during the Step 14 Evaluation, and the teacher will look for evidence of this idea. Keep this working definition on the board during the lesson.

Explore

3. Go back to the bicycle, and have students work in small groups to respond to the questions on the handout, *The Bicycle as a System*. In addition to the sample answers, other answers are also acceptable if justified by students:

   a) What is the function of a bicycle? (To go somewhere. Note: this is a precursor to some of the "form and function" ideas you may encounter in future biology lessons.)

   b) Identify at least three parts of the bicycle. If you don't know the name of a part, make up a name. Tell what function each part has. (Sample answer – the seat provides a place for the rider to sit.)

   c) Can any one part of the bicycle carry out the job of the whole bicycle? Explain your answer. (No one part can do the job of the whole bicycle, because one part by itself can't take you somewhere.)

   d) Can a part be removed and have the bicycle still work? Explain your answer. (Some parts are not necessary and can be removed, such as a water carrier. If other parts, such as the chain, are removed, the bicycle won't work.)

   e) What parts of the bicycle must work together if you want to ride around a corner? (Handlebar, gears, pedals, possibly the brake. Point out that the ***interaction*** of parts makes turning the corner possible.)

   f) Could some parts of the bicycle be arranged differently and the bicycle still carry out its function? (Rearrangement of some parts would probably change the interactions and the overall way the bicycle works. A change in one interacting part impacts all the other parts.)

g) Can you identify a subsystem within the whole bicycle system? Describe the parts that make up this subsystem. (Example – the pedal has parts that work together to perform the function of a pedal.)

4. As you discuss group responses to the questions about the bicycle, pay particular attention to responses to (e); it is the interactions of components that make systems responsive to inputs and outputs.

5. Have students work in small groups, assigning each group an item that can be considered a system (see the materials list for examples). Distribute the handout, *Questions about Systems*. Have students work in their group to answer – and justify their answers to the questions. Answers will vary according to the system being analyzed.

6. Have each group share its answers with another group. If there are differences of opinion, have these discussed by the whole class. Note the commonalities of responses, even though each group had a different item. Also comment on the similarities to the bicycle questions.

7. Optional Homework: Have students choose an object at home and answer the questions on the *Questions about Systems* handout.

Explain

8. **Examples of systems in the natural world**
   Have students work in pairs to answer the same *Questions about Systems* prompts that they used for their manufactured object as they consider a living system:
   a) Take students outside and have them find examples of natural systems in their 'backyard'. (It is likely they will choose a plant, animal, or ecosystem such as a pond.)
   b) Or, "Hat Grab": Provide pictures of natural systems in your region, and have students draw from a hat.
   c) The "Hat Grab" can be used as a preview to an upcoming unit. For example, you could use pictures of ecosystems that you will be teaching this year.

9. Discuss the characteristics of the natural system. Explanation should emphasize the dynamic interactions between the components of the system, and how the physical components of this natural system interact, relate and respond to each other. The properties of the system are a result of the interaction of the components, rather than being a property of the separate parts. Then point out the addition of a

biological component to a natural system vs a manufactured system, and how this adds an additional level of complexity. Sometimes, scientists focus in on specific parts of a system, such the growth of algae in a pond, but they know they can't really separate all parts of one system from all parts of another because they influence each other.

10. This is a time when the ideas of "spheres" – lithosphere, atmosphere, hydrosphere, and biosphere – can be introduced. It is not necessary for students to memorize the terms, but their understanding of the interactions of components can be developed. Discuss how these systems are not mutually exclusive, and what happens in one of these "spheres" influences what happens in the other spheres (e.g. water cycles through the air, land, and water). When we talk about a system such as a weather system, we must include enough parts and examine a large enough region so the relationships to one another make some kind of sense. But we also define boundaries that help us to focus on a particular phenomenon. When communicating our thinking to others, it's important to explain the boundaries we have placed on our system.

11. Note: Subsequent lessons pertaining to weather and climate will expand upon the idea of boundaries. Once a system's boundaries are identified, the output from one part of a system (which can include matter or energy) can become the input to other parts. For the purpose of this lesson, the terms "input", "output", "open" or "closed" systems are not essential; it will suffice to simply talk about "things coming in" and "things going out".

12. Identify a natural system from Step 8 that is an example of a system connected to other systems (e.g. some kind of ecosystem). Have students work in pairs to identify subsystems and also a larger system in which this example is "nested". Share some of the subsystems and larger systems that students identify, and note the commonalities and/or differences of the various examples. There is no single "right" or "wrong" answer to student examples, as long as students can justify the subsystems and larger systems in terms of interactions between components. The key point is that what happens in one subsystem influences another.

Elaborate

13. Elaboration will take place in the subsequent lesson series, "Weather and Climate", where students will use NOAA data to consider weather as a system. After that series, the Gulf of Maine can be brought in for consideration as a system, using the same questions about systems.

Evaluate

14. Have each student complete a journal entry:
    - Revisit the working definition the class developed at the beginning of this lesson. Based on your answers to the questions about systems, what did you learn that you could now revise or add to your definition? (The definition should focus not only on the parts of a system, but also on the interactions.)
    - List at least three characteristics that all systems have in common, whether they are living or nonliving.
    - Give an example of a system that contains a subsystem, and is also a part of a larger system. What makes each of these (the system, subsystem, and larger system) a system?

Possible Extensions

- Consider integrating the unifying theme of systems into content domains in a variety of contexts. Make explicit connections between systems thinking and life, Earth & space, and physical science ideas. Extend the systems thinking to mathematics and social studies ideas such as number systems, societal structures.

- Classroom "Systems" Concept Map: Place this year's content topics on signs on the wall. As the year progresses, create cards that can be posted on the wall, having students construct a systems map linking the concepts they are learning. Students can add connections throughout the year so that by the end of the year there is a big visual concept map of the systems they have learned. The connections between topics on the map should include linking words that explain why they are connected.

- Connect the unifying theme of systems to the idea of models and data collection. The purpose of studying systems is to develop the ability to think and analyze in terms of systems. Systems thinking can develop an understanding of the regularities in systems, which lead to an understanding of models that explain the world. Prediction from a systems perspective involves using knowledge about the world and an understanding of patterns and trends in data to identify and explain observations or changes in advance.

- Use the probe, "Is it a System?" to elicit student ideas prior to this lesson (Keeley and Tugel, 2009).

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The Bicycle as a System

a) What is the function of a bicycle?

b) Identify at least three parts of the bicycle. If you don't know the name of a part, make up a name. Tell what function each part has.

c) Can any one part of the bicycle carry out the job of the whole bicycle? Explain your answer.

d) Can a part be removed and have the bicycle still work? Explain your answer.

e) What parts of the bicycle must work together if you want to ride around a corner?

f) Could some parts of the bicycle be arranged differently and the bicycle still carry out its function?

g) Can you identify a subsystem within the whole bicycle system? Describe the parts that make up this subsystem.

Adapted from AAAS Project 2061 Lesson Plan, Seeing the Cell as a System:
http://www.project2061.org/publications/rsl/online/GUIDE/CH2/HLPSYS0.PDF

Questions about Systems

a) When this system is working, what does it do?

b) For this system to work, must it receive any input?

c) What, if any, output does this system produce?

d) What are the parts of this system? If you don't know the name of a part, make up a name. Tell what function each part has.

e) Can any one part of the system do what the whole system does? Justify your response.

f) Can a part be removed and have the system still function?

g) Identify at least two parts of the system that must interact if the system is to function. Describe how these parts interact.

h) Could these interacting parts of the system be arranged differently and the system still function?

i) What are the boundaries of this system?

j) Can you identify a subsystem within the whole system? Describe the parts that make up this subsystem.

k) Give an example of how this system might respond to a change in the environment outside the system.

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