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Lesson 1: Classification in Geometry

Introduction

Mathematicians and biologists study very different things. Mathematicians study numbers, patterns, and shapes, while biologists study plants and animals. But mathematicians and biologists both need to know how to sort and classify things, because it helps them understand how the things they study are related and how they work and are put together. And numbers, patterns, and shapes are present everywhere in nature, even in living things. So when you study the natural world, you end up using and discovering a great deal of mathematics.

Tell your students that in the next three lessons they will play a game called “What am I?” In this game they must act like detectives and try to find answers to various problems by asking the least number of questions possible. By playing the game, students will see how sorting and classifying things in a clever way can help them ask good questions when they are trying to solve a puzzle or a mystery. They will also see how mathematics is present everywhere in nature, and they will learn (in Lesson 3) how they can use their knowledge to help protect the environment.

Preparation

Place a selection of the shape cards from Blackline Master (BLM) 1: 2-D Shape Sorting Game (Intermediate) on the board and ask students to discuss what properties they might use to sort the shapes. You might have students work in groups, each with a set of shape cards. You might also give them rulers (to measure the sides of the shapes) or protractors (to measure the angles of the shapes) and you might also encourage them to fold the shapes to see whether they have any lines of symmetry.

When students think about how they would sort the shapes, they might consider the following sorts of questions:

- How many corners (or vertices) does the shape have?
- How many sides does the shape have?
- Are the sides all straight or are some sides curved?
- Does the shape have any square corners (right angles)? If so how many?
- Does the shape have any lines of symmetry?
- Is the shape equilateral (that is, are all sides of the same length)?
- Does the shape have any pairs of parallel sides? If so, how many?
- Does the shape have a special name?
- What kind of angles does the shape have (acute, obtuse, reflex)?

If your students are not able to describe the shapes using geometric terms, you might review the following terms:

- The sides of a shape are the lines that form the boundary of the shape.
- A vertex is a point where two sides of a figure meet.
- A square corner or right angle is an angle of the type found at the corner of a square (and is also called a 90 degree angle).
- A shape is equilateral if all of its sides are of the same length.
A line of symmetry is a line that divides a shape into two matching parts. To test whether a line is a line of symmetry, fold the shape along the line. If the two parts of the shape on either side of the line do not match up exactly, the line is not a line of symmetry.

The line shown in the diagram below is not a line of symmetry: even though the two parts of the figure are the same shape and size, they do not match up when the figure is folded along the line.

A square has four lines of symmetry but a rectangle has only two.

Lines are parallel if they are straight and if they would never meet when extended.

An angle is called acute if it is less than 90 degrees, obtuse if it is between 90 and 180 degrees, and reflex if it is between 180 and 360 degrees. Shapes E, G, K, M, and N all have one reflex angle.

A shape with three straight sides is a triangle, four sides a quadrilateral, five sides a pentagon, six sides a hexagon, and eight sides an octagon.

Some triangles have special names. A triangle is called equilateral if it has all equal sides, isosceles if it has two equal sides, and right angle if it has a right angle. Any shape, including a triangle, is called scalene if all sides are of different lengths. Shapes C and D are scalene.

Some quadrilaterals have special names. A square has four equal sides and four right angles. A rectangle has opposite sides that are equal and four right angles. A rhombus has four equal sides but not necessarily any right angles. Shape R is a rhombus, and so is shape F — a square. In a parallelogram opposite sides are parallel and of equal length. A square, rectangle, and rhombus are all parallelograms, as is shape I. A trapezoid, such as shapes J and Q, has exactly one pair of parallel sides. Figure K is a dart and figure L is a kite.

The Shape Game

Cut out shapes A, B, F, H, T, U, W, and X from the blackline master BLM 1 and post them on the board using sticky-tack or tape. Tell your students that you are thinking about one of the shapes. They must find out what shape you are thinking of by asking you questions, but you will only answer “Yes” or “No.” The goal of the game is to identify the shape by asking the least number of questions. (You might let one student at a time ask questions until they have found the answer, or you might allow students to take turns asking questions.) Students are not allowed to say the letter printed on the shape: they must identify the shape using geometric terms.

Play the game several times, keeping track of how many questions your students have to ask each time. Students should see that if they start by asking questions that are very specific, such as “Are you thinking of a square?”, they may have to ask many questions before they learn the answer. (As there are eight shapes, they might need to ask as many as seven questions this way.)

Ask your students whether they have a strategy for playing the game. Can they always find the answer by asking a certain number of questions? Students should see that if they are clever they only need to ask three
questions. The first question, for instance, might tell them whether the shape is equilateral or not, the second whether the shape has more than four sides, and the third the exact number of sides. Alternatively, students might first ask whether the shape has at least one square corner, and then, if the answer is yes, whether the shape has four sides, and then, if the answer is no, whether the shape has six sides. (One more question would be needed to identify the exact shape.) Ask your students whether they would be certain to get the answer in three questions if they just guessed the shape at random. (No, it might take seven questions.)

As students eliminate shapes by asking questions, you might remove the shapes from the board, to make it easier for students to focus on the remaining shapes. You might also ask students to help you identify the shapes that have been eliminated by a particular question.

Below is a series of games of increasing difficulty that can be played with the geometric shapes on BLM 1. You should pick the games that suit your students. Post the shapes in each game on the board and play the game exactly as you played the previous game. You might allow students to come to the board and lead the game by picking a selection of shapes and asking their fellow students to guess the shape they are thinking of.

Research in psychology has shown that students' brains work far more efficiently if they are confident and engaged. One way to build confidence is to “raise the bar” incrementally by asking students a series of questions that appear to be harder and harder but that do not require any new skills or knowledge to answer. Make a big deal of your students' successes as you play the games.

There are many ways to sort the shapes in the games below, but in each game it is possible to identify any shape by asking just two or three questions. For each game there are some suggested sorting attributes that students might use to sort the shapes.

Game 1

Shapes: A, B, O, P, W, X
Sorting Attributes: 3 sides/6 sides/8 sides or 3 vertices/6 vertices/8 vertices or triangle/hexagon/octagon; then equilateral/non-equilateral

Game 2

Shapes: A, B, N, X
Sorting Attributes: 3 sides/6 sides or triangle/hexagon; at least one line of symmetry/no line of symmetry or at least one square corner/no square corners

Game 3

Shapes: C, D, H, S
Sorting Attributes: 3 sides/4 sides or triangle/quadrilateral; scalene/not scalene

Game 4

Sorting Attributes: 4 sides/5 sides/6 sides; reflex angle/no reflex angle

Game 5

Shapes: E, G, M, N
Sorting Attributes: 5 sides/6 sides or pentagon/hexagon; 2 right angles/3 right angles

Game 6

Shapes: E, F, H, I, J, N, Q, V
**Sorting Attributes**: Shapes J, M, Q, and V all have one pair of parallel sides, while shapes H, I, N, and F have two pairs. Shapes J, M, Q, and V can then be sorted into two groups according to the number of sides (J and Q have 4 sides and V and M have 5 sides). Q has 2 square corners and J has none. M has a reflex angle and V has none. Shapes H, I, N, and F can be sorted into two groups according to whether they have a line of symmetry or not. Those two groups can be further sorted by the number of sides or the type of figure.

**Game 7**

**Shapes**: A, G, J, L, M, N, V, X  
**Sorting Attributes**: Shapes A, J, L, and M all have two acute angles, while the other shapes have none. Two of the shapes in the group A, J, L, and M have the same number of sides (four sides) as do two in the other group (six sides). Students could ask a variety of questions to identify the final shape.

**Note**: If you have a younger intermediate class and you would like a selection of easier games, see the Junior version of this lesson plan. For a more challenging exercise, put a random selection of shapes on the board and ask students to determine the minimum number of questions required to identify a shape.

For a bonus activity you might ask your students to draw a tree diagram to show how they would classify a particular set of shapes. An example of what a tree diagram for the introductory game (above) might look like is provided below.

![Tree Diagram](https://example.com/tree-diagram.png)

**Note**: JUMP Math is a charity dedicated to supporting teachers in the teaching of mathematics. JUMP has developed books and teacher’s guides covering the curriculum from grades 1 to 8. JUMP also provides professional development for teachers. See the website www.jumpmath.org for details. JUMP would like to thank the artist Roger Hall (www.wildlife-artworks.com) for donating the use of his animal illustrations for these lessons.
Introduction

In the last lesson your students learned how to sort shapes according to their geometric properties. In this lesson they will learn how biologists sort animals according to what they eat (or where they derive their energy). Knowing which animals and plants a particular animal depends on to survive can help scientists protect the animal and make sure that it is not harmed by human activities.

A food chain or food web is a diagram that shows which plants or animals are eaten by the animals in a particular habitat. There is a great deal of interesting mathematics in a food web, and understanding this mathematics will allow your students to understand in-depth how pollution, loss of habitat and climate change harm plants and animals.

Tell your students that since they are now all experts at asking good questions to solve a puzzle, you will give them a chance to solve some puzzles about nature. Solving these puzzles will help them learn to think like scientists. And when they can think like scientists, they will be able to find out for themselves how their actions affect the environment, and they will see how much power they have to protect the plants and animals of the world.

Food Chains and Food Webs

As a warm-up activity, post a selection of animal cards from BLM 3 on the board and ask your students to discuss how they might sort the animals. In thinking about the properties of the animals, students might ask the following sorts of questions:

- Does the animal have legs? If so, how many?
- Does the animal have wings? If so, how many?
- How does the animal move? Does it run, crawl, swim, or fly?
- Where does the animal live?
- What type of body covering does it have?
- Is the animal’s body segmented (like an ant’s or grasshopper’s)?
- Does the animal have a backbone? (Animals with backbones are called vertebrates and ones without are called invertebrates.)

After your students have had a chance to discuss these questions, remind them of one thing that all animals have in common: they must eat food to survive. Food gives animals the energy they need to grow, move, and reproduce.

Biologists are scientists who study animals and plants. Biologists can learn a great deal about an animal by finding out what kinds of things it eats.

Place the following animal cards on the board and draw arrows between them as shown:

- Tree → Caterpillar → Frog → Fish → Snowy Owl

(Note: In the diagram the animal names are arranged horizontally to save space. But you should place the cards on the board in a column, vertically, with the plant at the bottom. The cards are fairly small so you can create food chains that have a number of animals in them. Students at the back of the classroom may not be able to read the labels on the cards, but they should be able to recognize the animal on a card by its
silhouette. To help students recognize the cards from a distance, let them see them up close first so they can become familiar with the names of the animals. You might want to laminate the cards so they are easier to use, and so you can reuse them.)

Tell your students that the diagram you created is called a food chain. A food chain shows which plants or animals are eaten by the various animals in a habitat. In a food chain, the arrows always point from the food to the animal that eats the food. Leave the food chain on the board while your students help you with the following activity.

Place the cards below on the board in the order shown. Ask your students if they can arrange the cards in a column and create a food chain by drawing arrows to show which animals eat which food.

**Question 1:**  
Tree  
Robin  
Caterpillar  
Great Horned Owl  

**Answer:**  
Tree  $\rightarrow$  Caterpillar  $\rightarrow$  Robin  $\rightarrow$  Great Horned Owl

**Question 2:**  
Grasses  
Mouse  
Grasshopper  
Barn Owl  
Snake

**Answer:**  
Grasses  $\rightarrow$  Grasshopper  $\rightarrow$  Mouse  $\rightarrow$  Snake  $\rightarrow$  Barn Owl

Ask your students whether the three food chains have anything in common. Students might notice that each chain starts with a plant and ends with an owl. Tell your students that many food chains end with animals that are not owls, but very few start with an animal rather than a plant. Ask your students whether there could be a food chain where an animal is at the bottom and a plant appears above an animal. Your students may be surprised to learn that plants do sometimes eat animals! The Venus fly trap, for instance, eats insects by trapping them in leaves that have long spines along their edges that form a cage when the leaf closes. Once the insect is trapped, the leaf releases a chemical that dissolves the insect, thus allowing the plant to digest its prey. (Students might do a research project on the types of plants that eat animals.)

Tell your students that you put an owl at the top of each food chain for a reason. Scientists can learn a great deal about a habitat (a habitat is a place where animals live) by studying what owls eat. Owls eat a great variety of small animals, including insects, reptiles, birds, and mammals like mice and rabbits. Since owls don’t have teeth, they can’t chew their food the way we chew ours. Most birds that eat animals larger than insects, like hawks, shred their prey with their beaks, because this helps them digest the food. But some owls, like the barn owl, don’t even do this: they swallow their prey whole! This means that owls usually digest less of what they eat than other birds. They regurgitate the parts of their prey they can’t digest in balls called “owl pellets.” If you pull open an owl pellet, you can sometimes find the entire skeleton of a mouse or a shrew inside. Because owls eat so many different kinds of animals, scientists can get a good idea of the types and numbers of animals that live in a particular habitat by examining the owl pellets.

Owls are amazing hunters. The barn owl, for instance, has special feathers that reduce the noise it makes when it flies so it can hover silently above its prey. It also has extremely acute hearing so it can hunt in the dark just by listening for the movements of its prey. (You might encourage your students to do a research project on owls and their importance in their habitats.)

Biologists call plants "producers" because they absorb the energy of the sun and store it in a form that animals can digest. Animals are called “consumers” because they use up or consume the energy that is stored in plants. In a food chain you can usually find three types of animals: animals that only eat plants, which are called herbivores; animals that eat other animals, which are called carnivores; and animals that eat both plants and animals, which are called omnivores. Since carnivores depend on herbivores to survive and herbivores eat plants, all animals (including humans) depend on plants to survive. That is why it is so important to protect the forests, meadows, and grasslands of the world and why it is important to grow plants in a way that doesn’t harm the environment.

Mix up the cards below and tell your students that there is an omnivore in the food chain they can make with the cards. So, once they have made the food chain, they will have to add an extra arrow from the plant to the omnivore.
Grasses → Grasshopper → Mouse → Snowy Owl

The level at which an animal occurs in a food chain has environmental significance, so biologists created special names for each level. Herbivores are called primary consumers, while animals that are one level above primary consumers are called secondary consumers. Then there are tertiary consumers, quaternary consumers, and so on. (It is rare for a food chain to have more than five levels, for a reason that will be explained later.) An animal can be a consumer at several levels in a habitat. For instance, in the food chain above, the mouse is both a primary and a tertiary consumer.

Ask your students to identify the producers, consumers, herbivores, omnivores, and carnivores in the food chains above, as well as the primary, secondary, and tertiary consumers.

Draw your students’ attention to the first food chain that you made for the snowy owl. Tell them that you are going to create a more complicated structure called a food web by adding animals to the food chain. Place the flower, butterfly, dragonfly, and duck cards on the board. Ask your students to make a food chain leading up to the snowy owl beside the first food chain, and then ask them to add any arrows they think might connect the food chains. The answer is shown in Figure 1. Then place the grasses, grasshopper, and mouse cards on the board and ask the students to repeat the exercise. The resulting diagram is shown in Figure 2. Tell your students that any diagram that combines several food chains is called a food web.

Tell your students that there is a great deal of interesting mathematics in the food web. Ask: What does the number of arrows that point away from a particular animal tell you? (How many animals in the web eat the animal.) What does the number of arrows that point to the animal tell you? (How many animals are eaten by the animal.) How many animals eat the caterpillar? (Two.) How many animals are eaten by the duck? (Three.) Which two animals eat the most animals? (The duck and the snowy owl.) How many animals are omnivores? (Two: the mouse and the duck.) Ask a number of questions of this sort to give students a chance to demonstrate their understanding of the web.

Knowing how many arrows point to and away from an animal in a food web can tell you how important the animal is in a habitat. An animal with many arrows pointing away from it provides food for many other animals. And an animal with many arrows pointing towards it can perform an important function by controlling populations of animals that might otherwise become too numerous and destroy the habitat. Caterpillars, for instance, would kill a great many trees if they weren’t eaten by the animals that are directly above them in the web. (Ask your students which animals in the web keep the population of caterpillars in check.) But caterpillars are important themselves as they provide food directly or indirectly for so many other animals. In a natural habitat, all of the animals and plants play a role in maintaining the health of the habitat.

Another important mathematical feature of a food web is called a “path.” To find a path, start at one of the organisms on the web and move along any arrow in the direction in which it points. (You are not allowed to move backwards along an arrow; all paths lead upwards.) If you follow a set of one or more arrows in a row, you will have found a path in the web. Ask a student to identify a path from the grasses to the snowy owl by naming the animals along the path. Ask another student to find a different path from the grasses to the snowy owl. (Paths are considered different as long as one of the paths has at least one different organism on.
it, so paths that are different may still overlap. For instance, “grasses, grasshopper, mouse, snowy owl” and “grasses, mouse, snowy owl” are different paths.) How many paths are there from the flower to the snowy owl altogether? (There are four.) From which plant are there the least number of paths to the snowy owl? (There are three paths from the grasses, and four paths from both the tree and the flower.)

The length of a path is the number of organisms you encounter as you move along the path. For instance, the path “caterpillar, mouse, barn owl” has length 3, since there are 3 animals along the path. Ask students to count the length of several paths on the web. Then ask: How long is the longest path from a plant to the snowy owl? (There are two paths of length 6; for instance, flower, butterfly, dragonfly, frog, duck, fish, snowy owl.) How long is the shortest path? (There are two paths of length 3.) What is the most common path length? (5.) For a real challenge: What fraction of the total number of paths are of length 6? (From this fraction students can see that long paths are relatively rare.)

Ask your students to think about how paths might be important in a food web. If you follow all the paths that lead upwards from an organism, you will find all the animals that derive the energy that they need to survive from the organism. How many animals in the web derive energy from the frog? (Three: the fish, the duck, and the snowy owl.) How many derive energy from the caterpillar? (Five: the frog, the fish, the mouse, the duck, and the snowy owl.) From which animal do the greatest number of animals derive energy? (The caterpillar.) From which plant do the greatest number of animals derive energy? (The tree.) You might point out to your students that the relations of interdependence in a habitat are even more complex than those they can see from the web. For instance, plants also depend on animals to survive: flowers, for instance, depend on bees to spread their pollen, and trees depend on animals like squirrels and chipmunks to spread their cones, nuts, and seeds.

From the web, students can begin to see how human activities affect the environment. They can see, for instance, how many animals are harmed when trees are cut down or grasslands are destroyed. They can also see how pollution and poisons spread through a habitat. Farmers spray pesticides on crops to control insects like caterpillars and grasshoppers. The chemicals in pesticides are stored directly in the body of an animal that eats the pesticide, but they are also stored in the body of a second animal that eats the first, in the body of a third animal that eats the second, and so on. So the chemicals in pesticides, which can be harmful to humans as well as animals, work their way upward along any paths in the web. How many animals in the web are affected if a caterpillar or a grasshopper eats a plant that has been sprayed with pesticides? Your students should see that all but one of the animals are affected, because every animal can be reached from a path that starts from the caterpillar or the grasshopper!

Let your students know that the length of the path in a food chain has another important environmental implication. At each level in the food chain, much of the energy of the sun that is stored in plants is lost. In the next lesson they will learn to estimate how much energy is lost and about the environmental consequences of this loss.

Let your students know that food chains are an example of a very important structure that mathematicians call a “directed graph.” Directed graphs have many applications in mathematics as well as in computer science, business, and in the sciences in general. To make a directed graph from a food chain, just replace each animal card with a dot (called a “vertex”). The arrows on the graph are called “edges” or “directed edges.” (See below for an example.)

A directed graph can represent many things besides a food chain. It can represent a set of airline routes (the dots represent cities and the arrows show which cities you can fly between) or links between websites (the dots represent websites and the arrows show which websites are connected to other websites by links) or the order of a set of tasks (the dots represent the tasks and the arrows show the order the tasks must be done in).

Put several food webs on the board and allow your students to practise drawing directed graphs from the food web. The directed graph for the snowy owl food web in Figure 2 is shown below. (If your students find this exercise hard, start with very simple food webs.)
End the lesson by playing the game from the previous lesson but using the animal cards rather than the shape cards. Put a selection of animal cards on the board, arranged in a food web, and ask students to identify the animal you are thinking of by asking questions. Students should ask questions that are based on the food web and on the terms and concepts they learned in the lesson. For instance, if you use the food web for the barn owl from Figure 2, they might ask: Are you thinking of a producer? A consumer? A herbivore? A carnivore? An omnivore? An animal that is both a primary and a tertiary consumer? An animal that derives its energy from a dragonfly? An animal that is eaten by two other animals? And so on.

As a warm-up game you might try using the food web below. You might also ask students to draw a tree diagram to sort the animals. An example is shown in Figure 5. (Note: The properties in the tree diagram are some of the properties students might use in their questions.)

Tell your students that now that they understand some of the mathematics of food webs, they are ready to start applying their knowledge. In the next lesson they will look more deeply at how directed graphs can be used to understand the environment and will learn about some things they can do at home and at school to help protect all the plants and animals that live in the same part of the world that they do.
Lesson 3: Applying the Mathematics of Food Webs

Introduction

In this lesson your students will investigate the mathematics of food webs more deeply. Understanding the mathematical structure of food webs can help students develop a greater respect for the complex and delicate balance of nature. Students will discuss ways in which their own activities affect animal food webs and, more generally, ways in which the balance of nature may be upset when people fail to think about the environment in a scientific way.

The lesson concludes with a game called “What Am I?” in which students can apply all of the things they learned about food webs.

Why the Math in Food Webs Matters

Start by reviewing the concepts about food webs that you covered in the last lesson. Then ask your students to discuss how these concepts might be relevant to the environment. Some questions that you might use to guide the discussion are provided below.

Remind students that “vertex” is just a mathematical name for a dot or point. A vertex on a graph can represent anything: for a biologist studying a food web it can represent an animal; for an airline scheduler it can represent a city that the airline flies into or out of; for a computer programmer it can represent a task that the computer must do in a certain order; and for a sports scheduler it can represent a game that must be played before or after another game. A “directed edge” on a graph is just an arrow pointing from one vertex to another. In a food web, the arrows or directed edges always point from the food to the animal that eats the food. You might put two versions of the same food web on the board (one with animal cards and one with vertices representing the animals) that you can refer to in the discussion.

1. What does the number of arrows (or edges) pointing towards or away from a vertex on a food web tell you, and how is this information important?

   The number of edges pointing to a vertex representing an animal tells you how many animals that animal eats. The number of edges pointing away from a vertex tells you how many animals eat the animal.

   An animal with many arrows pointing away from it provides energy directly to many other animals in the web. As a result, changes in the environment that affect that animal also affect many other animals in the web.

   An animal that has many arrows pointing towards it is one that consumes many other animals. These kinds of animals can be very helpful to humans. For instance, owls consume a great variety of rodents (rats, mice, shrews, and voles) and insects that eat farmers’ crops. Barn owls can be more effective at controlling the various animals that farmers consider pests than pesticides or poisons. Having a family of barn owls on a farm is much healthier for the environment than having a barn or field full of potentially harmful chemicals.

2. Why is the length of the longest path in a food web important?

   All animals ultimately depend on the energy of the sun that is stored in plants. At each level of the food web, much of the energy that can be used to sustain life is lost. You can get an idea of how much energy is lost if you look at an owl pellet. Recall from the last lesson that you can find entire skeletons of small animals in owl pellets, as well as hair and other indigestible materials. All of this matter, which may have
come from a mouse or a frog, contains energy that the mouse or frog absorbed from smaller creatures but that the owl can’t use. So you can see how much energy is lost at each level in the food chain. That’s why several acres of forest or meadow can support only a few animals at the top levels of a food chain. Therefore, to protect animals like owls, hawks, lynxes, and bears, humans must preserve large areas of wilderness and keep them free from pollution and development.

(Later in the lesson your students will learn to calculate how much energy is lost at each level in a food chain, and they will discover some surprising implications about how and what they should eat if they want to protect the environment.)

There is another reason why long food chains are important to humans. Because so much energy is lost at each level, animals that are at the top of the food chain must consume large masses (relative to their body weight) of the animals that are below them.

Barn owl babies can eat their own weight in food each day. How many kilograms of food would you have to eat in a day to eat your own weight? About how many kilograms do you normally eat in a meal? Probably not more than one or two. How many meals would you have to eat in a day to eat your weight in food? Can you estimate how much time you would have to spend eating each day to consume food at the same rate as a baby barn owl? When would you find the time to do your homework?

If the animals and plants at the bottom of a food chain absorb any harmful chemicals from pollution or pesticides, these chemicals will become more and more concentrated in animals’ bodies as you move up the food chain (because animals high in the chain consume so much of what is below them). Even chemicals that are weakly concentrated in the bodies of small animals and plants can pose a threat to the people and animals who eat those animals and plants. That is why, for instance, the government warns people not to eat fish from some of the Great Lakes, because the chemicals that we put into the water have become so concentrated in those fish. The longer a food chain is, the more concentrated the chemicals that humans introduce into the environment will be.

3. Why is it important to know what vertices you can reach on a graph by following a path from a particular vertex?

If you start at a particular animal on a web and follow all the paths that lead away from that animal, you find all the animals that depend on the animal for their food energy. If the animal is harmed by human activities, then all the animals in the web that can be reached from that animal suffer. Following paths on a food web will also tell you where the chemicals that an animal eats or absorbs will become concentrated.

The frog is one of the most important animals in many Canadian food webs, because many other animals, like fish and owls, depend on it for food. But the frog is also one of the Canadian animals that is most vulnerable to changes in the environment, because it is an amphibian. Amphibians like frogs and salamanders develop from eggs laid in water. When they are young they breathe water through gills, like fish do, and when they are older they develop lungs and breathe air, like we do. (Imagine spending your childhood breathing water and then learning to breath air!) Amphibians have extremely sensitive skin that easily absorbs the pollution and pesticides that people put in water. Populations of amphibians have declined all around the world because the marshes and ponds they depend on are being polluted or developed by humans. As a result, animals that are higher up in food webs have less to eat. (Frogs are also important because they eat vast numbers of insects. The fewer frogs there are, the more people rely on pesticides to control insects.)

4. If you remove enough vertices from a graph, you can “disconnect” it so that a set of the remaining vertices cannot be reached from another set. Why is it important to know which sets of vertices will disconnect a graph when they are removed?

Suppose there is a set of animals that disconnect a food web when you remove them. If those animals were to become extinct, then all the animals that are above them in the food web would also become extinct (unless they had some other sources of food), because they would become disconnected from the energy of the sun that is passed through the food web.
Tell your students that you will now give them a chance to develop their understanding of food webs by identifying all of the structures you have discussed. This exercise will help them play the game that you are saving for the end of the lesson.

Draw the graph in Figure 1 on the board and ask your students the following questions.

![Figure 1](image)

How many edges point towards vertex D? (Two.) How many point away? (Four.) How long is the longest path on the graph? (Six vertices long.) How many paths are there of this length? (One path: B, D, E, H, G, I.) How many paths can you find from the bottom to the top of the graph that are four vertices long? (Warn your students that this is a tricky question. To find all the paths they will have to work systematically, starting at one of the bottom vertices and not moving on until they have found all paths from that vertex to the top of the graph. There are eight paths altogether.) Which vertices can you reach from vertex C? (F, G, and I.)

Give your students a copy of BLM 2: Directed Graphs (Intermediate). Ask them to answer the following questions in a notebook. Students needn’t answer every question for every graph; you might give students a fixed amount of time to work on the graphs, but don’t make it a competition to see how many they can finish.

1. How many edges point towards vertex F?
   
   **Answers:** For G1, two edges; G2, three edges; G3, one edge; G4, one edge

2. How many edges point away from vertex F?
   
   **Answers:** For G1, no edges; G2, one edge; G3, three edges; G4, one edge

3. What is the length of the longest path?
   
   **Answers:** For G1, 5 vertices long; G2, 5 vertices; G3, 6 vertices; G4, 6 vertices

4. How many longest paths can you find?
   
   **Answers:** For G1, 1 path; G2, 2 paths; G3, 5 paths; G4, 2 paths

5. Which vertices can you reach from vertex C?
   
   **Answers:** For G1, E, D, and F; G2, F and G; G3, E, H, and K; G4, F, I, K, L, H, and J

6. What is the minimum number of vertices that you need to remove to disconnect the graph?
   
   **Answers:** For G1, 2 vertices (For example, if you remove vertices B and C, and all of the edges that end or begin at B and C, then vertex A becomes disconnected from vertices D, E, and F.); G2, 2 vertices (If you remove B and F then C becomes disconnected from the rest of the graph.); G3, 1 vertex (If you remove B then A becomes disconnected.); G4, 1 vertex (Remove E, F, or I and the graph becomes disconnected.)

After students have completed the exercise above, tell them that you would like to look more closely at the environmental consequences of some of the concepts they have learned.

Scientists have determined that only a tenth of the energy that is stored at a particular level in the food chain
is passed on in a form that is usable at the next level. This means that if a given area of land can support 1000 kilograms of plants, it can support only about 100 kilograms of animals that eat the plants, 10 kilograms of animals that eat those animals, and 1 kilogram of animals that eat those animals. Also, because animals at each level must eat such a great volume of animals at the lower levels, harmful chemicals become ten times more concentrated at each level.

Ask students to discuss some of the things that they do at home or at school that might introduce harmful chemicals or substances into animal food webs or that might affect animal habitats. They could make a list of some of the things they might do that would reduce their impact on the environment.

Here are some examples of topics you could discuss.

1. Only a tenth of the energy in grain is absorbed when an animal eats the grain. So to produce just 1 kilogram of usable energy in meat, how many kilograms of grain do we need to grow? (10 kilograms.) If we eat 1 kilogram of grain directly (rather than the kilogram of meat), about how many kilograms of wheat do we save? (9 kilograms.) How many kilograms of grain would be saved if you replaced only 10 kilograms of meat in your own diet with 10 kilograms of grains or vegetables? (90 kilograms, which can be rounded to 100 kilograms for the calculations below.) Think about the weight of meat that you consume in an average meal. About how many meals would it take you to consume 10 kilograms of meat? How many times would you have to skip meat to save about 100 kilograms of grain? How many times to save a tonne? Could you save a tonne of grain in a year? As a research project, older students might investigate how much land would be required to grow that grain and how many kilograms of pesticides would normally be used on that land. Fact: U.S. livestock consumes about seven times as much grain as Americans do themselves. (Source: Inkling Magazine website.)

(Make sure your students know that the numbers above are rough estimates and that the amount of energy saved in replacing meat with vegetables will vary.)

2. Pesticides are widely used in Canada to kill insects. The chemical DDT was widely used to kill insects in the 1960s but is now banned in North America because scientists eventually discovered that birds in the top levels of food webs had so much DDT in their bodies that they were laying eggs with extremely thin shells that would break before they were hatched.

Many pesticides have long “half lives.” That means that it takes a long time before even half of the pesticide is broken down into a harmless form. DDT has a half life of 10 to 15 years. That means that if one tonne of DDT was sprayed on a particular area, 500 kilograms of the substance would still be present in the area 10 to 15 years later, and 250 kilograms would be present 20 to 30 years later. (How much would be present 40 to 60 years later? Answer: Half of 250 kilograms, which is 125 kilograms.)

Pesticides with long half lives have been discovered as far away as the Arctic and Antarctic; they were carried there on soil particles by the wind.

Figure 2 shows some concentrations of DDT that were found in marine animals (Source: Environmental Science, E. Enger, B, Smith, WCB Publishers, Chicago, 1995). The amount of DDT in the animals is measured in parts per million. A part per million is a unit of measurement used to describe the concentration of substances in soil, or water or tissue. If there is 1 part per million of DDT in an animal’s tissue, that means that there is 1 milligram of DDT in every kilogram of tissue. Since there are 1000 milligrams in a gram, this is equivalent to saying that there would be 1 gram of DDT in 1000 kilograms (a tonne) of tissue. This may seem like a very small amount, but to see that it isn’t, consider this: An elephant can weigh 40 tonnes. Imagine feeding an elephant 40 grams of poison!
Let your students know that concentrations of harmful chemicals don’t always increase ten times as you move from one level in a food chain to another; this is just a rough estimate. Ask your students to check whether the concentration of DDT in the animals in the food web in Figure 2 actually increase by a factor of ten as you move up each level. To make it easier for students to check this, remind them that if they want to compare a pair of decimal numbers they can multiply each number by a power of ten (that is, by 10, 100, 1000, etc.) to shift the decimal. For instance, to compare the numbers .17 (for the fish) and .08 (for the water plants), students could multiply each number by 100 to shift the decimal two places. Then they could compare the numbers 17 and 8 and see that the concentration of DDT increases by a factor of about two times between the plants and the fish (since 8 divides into 17 about two times).

**Note:** If your students don’t know why the decimal shifts to the right when they multiply a number by 10 or 100, review the meaning of decimal notation. The decimal notation 0.1 (also written 0.10) stands for an amount that fits into a whole ten times. A dime fits into a dollar ten times, which is why a dime is written $0.10 (the dollar is the whole). If you take an amount that fits into a whole ten times, and you multiply that amount by ten, you will get the whole. For instance, if you take ten dimes you will get a dollar, because by definition a dime fits into a dollar ten times. That is why when you multiply 0.1 by 10 you get 1.0 (or 1.00). Similarly, the decimal notation 0.01 stands for something that fits into the whole 100 times. A penny fits into a dollar 100 times, which is why it is written $0.01. If you take an amount that fits into a whole a hundred times and multiply it by 100, you will get the whole. For instance, if you take 100 pennies you will get a dollar, because by definition a penny fits into a dollar 100 times. That’s why when you multiply 0.01 by 100 you get 1.00.

Ask your students whether they can find an example in the chart where the concentration of DDT increases between levels by about ten times. (*Answer:* Yes, the rate of increase between the plankton and the clam is about ten times.) Can they find an example where the concentration increases by more than ten times? (*Answer:* Yes, there are several examples. For instance, the concentrations for the clam and the ring billed gull are .42 and 75.5 respectively. Multiplying both numbers by 100 gives 42 and 7550. Rounding 7550 to the nearest thousand gives 8000 and 42 to the nearest ten gives 40. Dividing 8000 by 40 gives 200. So the rate of increase is almost two hundred times!)

3. Ask your students to discuss the ways they use water at home and at school and to list some things they do that might cause the water to be less clean for animals. Often the products that clean clothes or floors or dishes make water less clean for animals. How can “cleaners” make water less clean?

Here is an example of how this happens. Many brands of laundry soap contain chemicals called phosphates. Phosphates cause a plant called “algae” (the green slime you see in dirty aquariums) to grow out of control in lakes and streams. In lakes where there is too much algae, fish and other aquatic animals can’t survive. (That’s because the small organisms that feed on the algae multiply and use up the oxygen in the water that fish need to live.)

Fortunately, many stores now sell cleaners that don’t contain phosphates and other harmful chemicals. (Your class might do some research on where they could find cleaners that don’t harm the environment.)

4. Challenge your students to think of other ways they can protect the environment by protecting animal food chains and habitats.
To finish the lesson, play the following game. Give each student a copy of BLM 4: A Food Web, or place several copies of the web around the class where students can easily see it. Tape a copy of an animal card from the web on each student’s back. Students must find out what animal they are, by asking other students questions that are related to the food web. They might ask, for instance: Am I a producer? Am I a consumer? Am I a herbivore? Am I a carnivore? Am I an omnivore? Am I a primary consumer? A secondary consumer? A tertiary consumer? Do I eat grasses? Do I derive my energy from a frog? (Before the game, remind your students that an animal “derives its energy” from another animal if there is a path of arrows in the web that leads from the other animal to the animal that depends on it.) Students might write down their questions in a notebook and might also discuss the strategies they used in the game.

When the game is over, congratulate your students for the work they have done discovering so many ways in which living things are interrelated. And thank them for thinking so deeply about what they can do to preserve the complex and delicate balance of the food webs of the world.
Continued
BLM 3: Animal and Plant Cards

- Snake
- Frog
- Barn Owl
- Snowy Owl
- Great Horned Owl
- Hawk

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Butterfly

Mouse

Dragonfly

Deer

Wolf

Bear
BLM 3: Animal and Plant Cards Continued

Robin

Duck

Rabbit

Mink

Fish

Grasshopper
BLM 4: A Food Web

Great Horned Owl

Hawk

Frog

Robin

Bear

Wolf

Snake

Mink

Dragonfly

Caterpillar

Grasshopper

Mouse

Deer

Rabbit

Duck

Butterfly

Tree

Berry Bush

Grasses

Flower