the Creative Learning EXCHANGE

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Keystone Species in an Ecosystem

Using Connection Circles to Tell the Story

Revised Lesson 11 from the 2008 edition of The Shape of Change

by Rob Quaden, Alan Ticotsky and Debra Lyneis, illustrated by Nathan Walker

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Introduction

Ecosystems are built upon complex interrelationships among organisms and their habitats. Often, a change in the population of one species causes unexpected changes in other species. Understanding and representing a web of changes is challenging for the scientists who study them, let alone for readers who try to comprehend these complex situations. In this lesson, students read a chapter from a skillfully written science book and use connection circles to unravel a mystery of nature.[1]

As in previous lessons, students will frame their inquiry with these questions: What is changing? How is it changing? Why is it changing?

THIS ISSUE AT A GLANCE

How It Works

In her informative and entertaining book, ***The Case of the Mummified Pigs and Other Mysteries in Nature***,[2] Susan E. Quinlan has written fourteen true stories that describe the research of ecologists who puzzle out how and why ecosystems behave as they do. Readers discover the interesting and often surprising connections among organisms through the work of detectives who find clues to nature's riddles.

The chapter, *"The Case of the Twin Islands,"* examines why the ecosystems in the waters off two neighboring Aleutian Islands are so different. As students use connection circles to trace causal relationships in the story, they discover the role of a keystone species, a species vital to the stability of the whole ecosystem. Students learn how feedback loops maintain a delicate balance in an ecosystem and what happens when that balance is disturbed.

Procedure

1. Read "The Case of the Twin Islands," reprinted with permission in the

Connection Circles

The purpose of a connection circle is to help students focus on the problem presented by the author and to uncover its causes. Here is a quick overview:

- First, students briefly define the problem: What is the author concerned about? What is the main problem? What is changing over time?
- Next, how is it changing? In a few words, or with a quick behavior over time graph, students describe how the problem is increasing or decreasing over time.
- Finally, students look for elements in the story that contribute to the problem. They use a connection circle to organize their thoughts, find cause and effect relationships, and trace the feedback loops that tie them together to explain why the problem occurs.

Connection Circles continued on page 3

EDITORIAL

After a long and very snowy winter, the snowdrops are up, battling with the sub-zero-to-50° fluctuating temperatures here in the Northeast. The snow piles have melted down to almost nothing (except for the ones made by snowplows, which are still so tall they could be here until May!) Unless we get another snowstorm, we are on the road to spring. Many of you are basking in the warmer days and beautiful spring flowers. I envy you!

This spring we are ramping up for the CLE conference, June 28-30, in Wellesley, Massachusetts, at the Babson Conference Center. It is going to be quite an international affair, with interest in ST/SD in K-12 education coming from Europe, Africa, and Asia. We are greatly excited and delighted by such widespread interest!

As always, it makes tremendous sense to come to the conference with your colleagues. The learning generated within each of you and amongst you can become a reinforcing feedback loop to create substantial growth and change. Come and bring at least two friends for an interesting, growing experience. We look forward to seeing both new and familiar faces.

Have a productive end of the school year. See you soon!

Take care,
Lees Stuntz
(stuntzln@clexchange.org)

The Climate Challenge: Our Choices

Drew Jones
Sustainability Institute
With overall team: Tom Fiddaman, Michael Tempel, Linda Booth Sweeney, Peter Senge, John Sterman, Juan F. Martin, Susan Sweitzer, Idit Caperton, Susan Randel

In the Winter 2007 issue of *The Exchange*, we printed a summary of activities using system dynamics to address climate change. The online simulation discussed in that article has been completed and is available at http://www.seed.slb.com/en/scictr/watch/climate_change/challenge.htm

Below are some FAQs and answers, as well as coach notes to help use, present, and explain the simulation.

CO2 and Climate Change

The amount of carbon dioxide (CO_2) in the atmosphere is increasing. The world is getting warmer. If this continues, the ecosystems and economies of the world will be dramatically altered. What can be done about this? In a computer simulation, we use water in a bathtub to represent CO_2 in the atmosphere. Can you keep the bathtub from overflowing?

We know that carbon dioxide (CO_2) is increasing in the atmosphere from human activities such as burning of fossil fuels and deforestation. This increase is one of the major factors in global warming. There is no longer any scientific debate about this. The most recent report by the Intergovernmental Panel on Climate Change has confirmed this.

In our simulation, the bathtub can overflow if the amount of CO_2 in the atmosphere increases to the point of significantly altering the climate. So what do you think we should do? Play the game to see if you can figure out how to stop global warming.

Climate Bathtub Sim Coach Notes and FAQs

Important Learning Practices

- Always elicit learner's thinking and estimates before running the model.
- Ask questions to gauge what the learner understands and does not.
- Let the learner click the buttons.

Overall Flow

1. Explain basics of carbon cycle

Explain briefly how the carbon cycle works. The key points are:

- There are human-based emissions from two sources – burning fossil fuels and from deforestation. We'll call them "emissions."
- There are also removals into oceans, plants, and soils.
- Emissions are much larger than removals.
- The excess between the two accumulates in the atmosphere.

Climate *continued on page 9*

Keystone Species in an Ecosystem

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Appendix of ***The Shape of Change*** (2008) beginning on page 137. Students may read independently, share reading, or listen to it read aloud.

2. Create connection circles summarizing the situation described in the story. If students are drawing connection circles for the first time, follow the procedure detailed in Lesson 10, "Do You Want Fries with That?" in ***The Shape of Change***.

If students are already familiar with connection circles, give each student a Connection Circle Template (page 133), review the rules, and ask pairs of students to begin choosing elements for their circles. See the Appendix (page 134) for a larger copy of the rules to post in your classroom for easy reference.

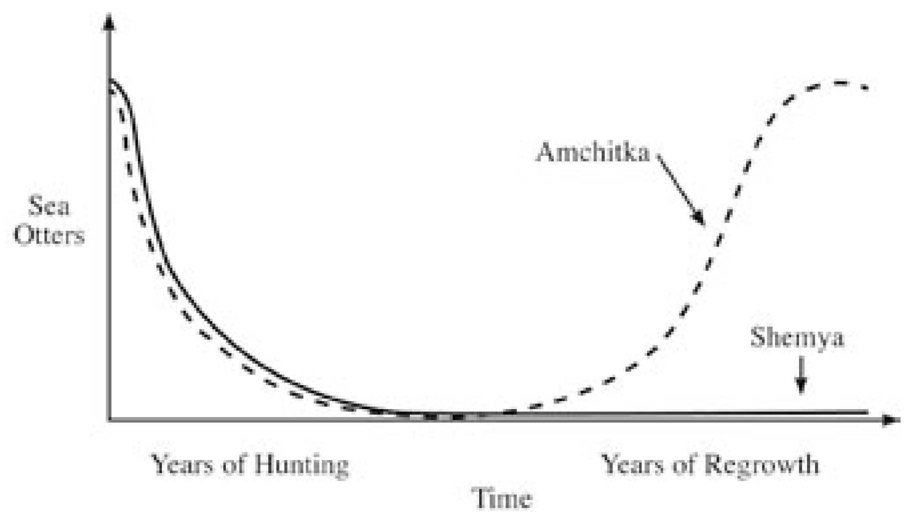
3. **What's the problem?** What is changing? Ask students to quickly identify the problem that the author is presenting. They may say, "The sea otters have disappeared from the waters around Shemya while the sea urchin population has grown there."

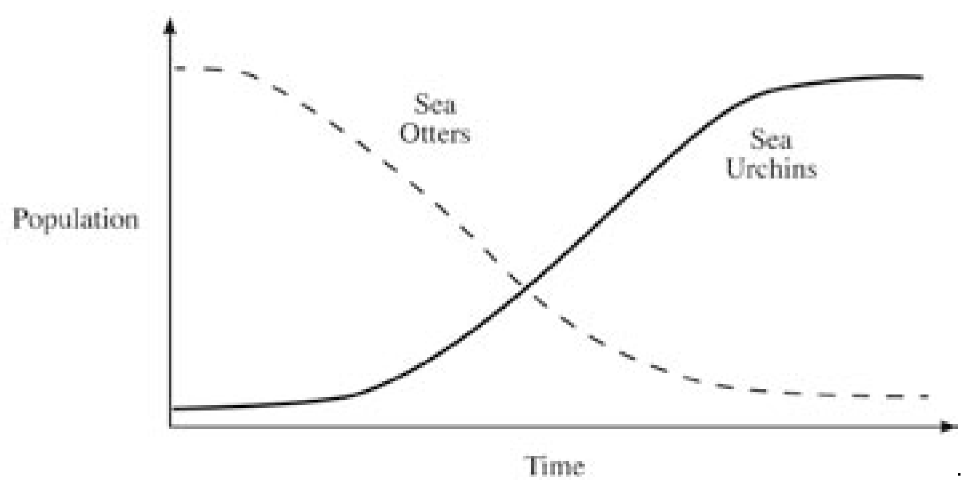
Ask students to define the problem more precisely by describing how the populations changed over time in a graph or briefly in words. The examples here are just quick rough sketches of the general patterns of behavior. (Students may prefer to sketch separate graphs for each population.)

4. Remind students to choose elements that describe the problem and its possible causes. Here, our main concern is the sea otter population that has decreased over time. The population of sea urchins is also important. Other variables in the story contribute to the increase and decrease of these species.

Materials

Overhead projector or display board
Several different colored markers for each student
Connection Circle template for each student
Posted copy of "Connection Circle Rules"
Copies of "The Case of the Twin Islands" from The Shape of Change (2008), page 137.





A behavior over time graph is a line graph sketch that shows how something changed over time. What was the general pattern of the behavior?

***Connection Circles** continued on page 4*

Keystone Species in an Ecosystem

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Precise language and clear thinking go hand in hand with connection circles.

- Elements must be nouns or noun phrases, quantities that can increase or decrease over time, like the number of sea otters or the amount of sand deposited.
- Do not use words like "more" or "less" in the titles.
- Remember that elements can be tangible, like the number of fur traders, or intangible, like the desire to protect the environment. Often the intangible variables are keys to the problem.
- Connection circles may vary. The words around each circle do not have to be the same nor in the same order, but they should all be things that work together to contribute to the problem.
- Students are always free to change, add or delete elements as they refine their thinking.

CONNECTION CIRCLE RULES

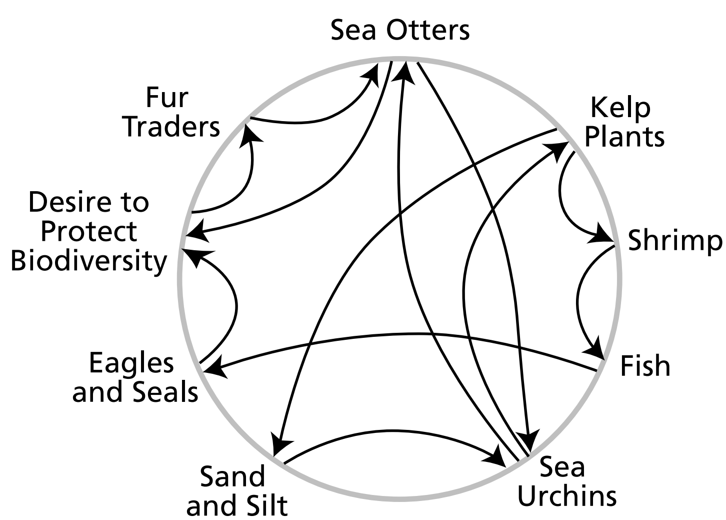
1. What's the problem: What is changing? How is it changing?
2. Choose elements of the story that satisfy all of these criteria:
   - They contribute to the problem.
   - They are nouns or noun phrases.
   - They increase or decrease over time.
3. Write the elements around the circle. Include no more than 5 to 10.
4. Find elements that cause another element to increase or decrease.
   - Draw an arrow from the cause to the effect.
   - The causal connection must be direct.
5. Look for feedback loops. Tell their story.

5. Once students have drawn their connection circles with causal arrows, share them as the focus of a class conversation.

- Draw a large circle on the board or overhead projector.
- Have each team suggest an element to put on the circle.
- As a class, refine the list to include *no more than five to ten elements.*
- Ask each team to describe a causal arrow and explain their reasoning for direct causality. Encourage other teams to ask clarifying questions. Students should refer to the text when explaining their reasoning.

Here is one example of a connection circle for *"The Case of the Twin Islands."* Expect student examples to vary.

Elements can be tangible or intangible. Do not use words like "more" or "less" in the labels. You may want to review the more detailed instructions in Lesson 10, "Do You Want Fries with That?"



Ask students to explain their arrows: How did a change in one element cause a change in another?

- An increase in the number of fur traders caused a decrease in the number of sea otters because traders hunted and killed sea otters. Also, a decrease in traders caused an *increase* in sea otters because they could multiply unharmed.

- An *increase* in the shrimp population caused an *increase* in the number of fish because fish eat shrimp. A *decrease* in the number of shrimp caused a *decrease* in the number of fish.

- An *increase* in kelp plants caused an *increase* in sand and silt because kelp calmed the waters allowing sediment to be deposited. The increased sediment then buried the sea urchins causing them to decrease. Students might draw an arrow suggesting that an increase in kelp caused a decrease in urchins, but this is not a *direct* cause. Remind students to be very careful in their thinking about what caused what.

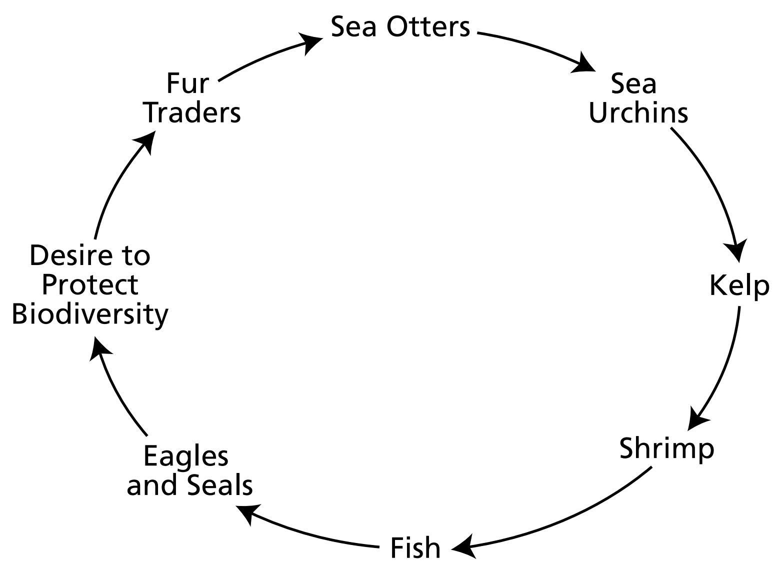
Remember, these are only sample drawings. Let students present their own ideas and encourage them to weigh the ideas of others. Students are always free to change their drawings as they continue to refine their mental models together.

6. Ask teams of students to trace a closed "loop." Can they start at one element, follow the arrows around the circle and return to where they started? Each of these pathways is a feedback loop that tells part of the story. Trace each loop in a different color. (It helps to start with an element that has many connections to and from it.)

After students trace a loop, ask them to draw a simplified drawing that includes only the elements from the traced loop, as shown in the following examples. Again, student drawings will vary.

Don't present these examples to students. Allow them to discover the feedback in the story for themselves. Have representatives from each team present feedback loops and share their team's stories with the class.

The circle below shows one large feedback loop. *Tracing the feedback loop reveals why the problem occurred; don't skip these steps.*



Starting at the top, an *increase* in sea otters caused a *decrease* in sea urchins because sea otters eat urchins. Fewer urchins allowed the kelp plants to *increase*. An *increase* in kelp caused an *increase* in shrimp, which then caused an *increase* in fish, which then caused an *increase* in eagles and seals. With abundant wildlife, people were less worried about biodiversity. A *decrease* in the desire to protect biodiversity allowed the number of traders to *increase*, so the number of sea otters began to *decrease*.

This is a **balancing feedback loop**. We started with an increase in sea otters, but going around the loop, the chain of events caused sea otters to decrease. If we traced the loop again, the decrease in sea otters would then become an increase, balancing back and forth each time around the loop.

Students trace the different loops on their original connection circles in different colors before drawing separate feedback loops. They can draw these loops freehand without using connection circles as templates.

The story gets complicated, but don't worry. It is easier when students construct and talk about their own circles. This is the reason for doing connection circles in the first place: Students can understand and communicate ideas that are difficult to express using more conventional tools.

Connection Circles *continued on page 6*

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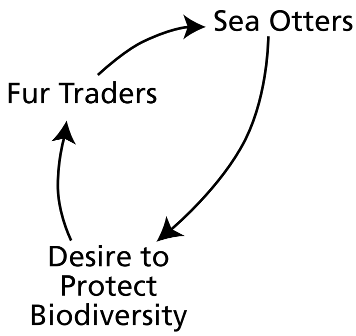
7. Look for other feedback loops. Here are some examples:

Otters and Fur Traders

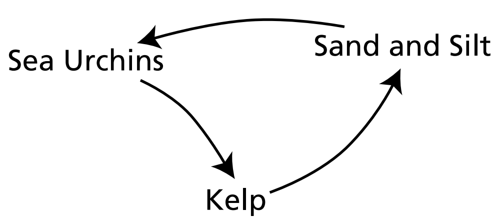
Here is a possible loop linking otters and fur traders.



Tracing the loop, an *increase* in fur traders in the 19th Century caused a *decrease* in sea otters to dangerously low levels. An awareness of the decline caused an *increase* in the desire to protect biodiversity. This led to a *decrease* in hunting. This is also a balancing loop – any change works to restore itself around the loop again.

Sea Urchins and Kelp

Here is another feedback loop. Sea urchins eat kelp plants. The kelp plants calm the water movement and trap sand and silt on the ocean bottom. Sand and silt smother sea urchins.



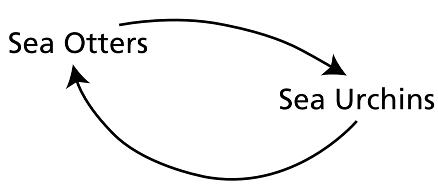
Tracing the loop for the circumstances around Shemya Island, an *increase* in sea urchins caused a *decrease* in kelp plants. Fewer kelp plants meant less sand was deposited. A *decrease* in sand provided a more suitable habitat for a *further increase* in sea urchins and *another decrease* in kelp plants. In this spiral, the sea urchins continued to multiply and the kelp disappeared.

However, around Amchitka Island, the opposite occurred. An initial *decrease* in sea urchins caused an *increase* in kelp plants. More kelp caused more sand. More sand meant *even fewer* sea urchins and *more and more* kelp. This time the spiral drove the sea urchin population *down* and the kelp thrived to harbor greater biodiversity.

This is a good example of a **reinforcing loop** — sometimes also called a virtuous or vicious cycle. Any change gets amplified over and over again, spiraling either up or down.

Sea Otters and Sea Urchins: Predators and Prey

Because sea otters prey upon sea urchins, an increase in sea otters causes a decrease in sea urchins. A decrease in urchins then causes a decrease in otters as their food supply dwindles. Tracing around the loop again, a decrease in otters allows the urchins to reestablish themselves. This is another balancing loop – any change restores itself, balancing back and forth each time around the loop.

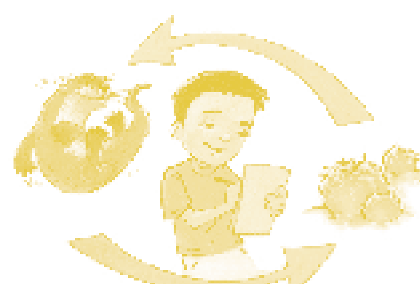


This feedback loop is typical of predator/prey feedback loops in nature. The populations balance each other. Too many predators will reduce the prey population to levels that will cause the predators to run short of food. When the prey population expands too much, more predators will hunt them and bring down their numbers.

Feedback Loops

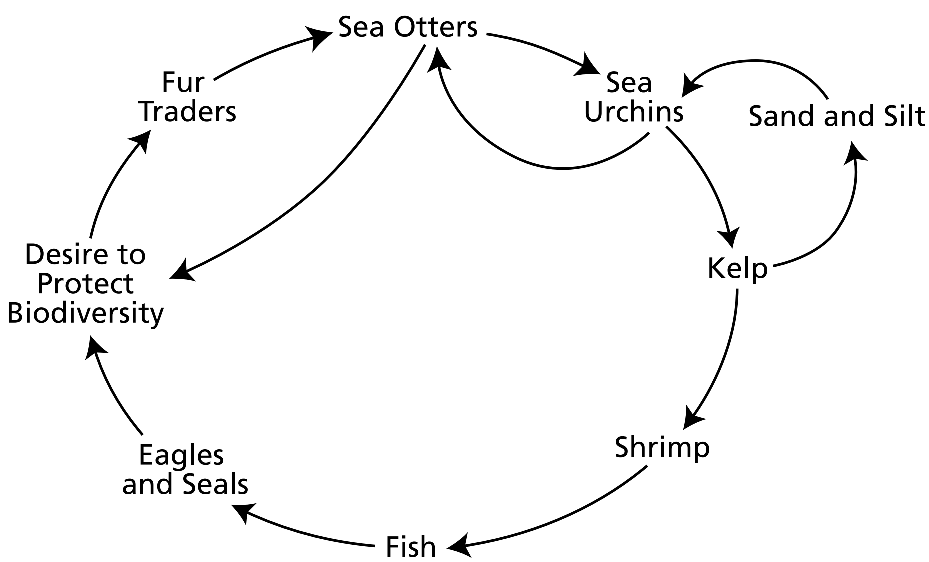
Reinforcing loops drive accelerating growth or decline in systems.
Balancing loops work to keep reinforcing loops in check. When something disrupts this delicate balance in an ecosystem, a reinforcing loop can spur a rapid growth or decline of a species – a clue to the mystery in our story.

Remember, a connection circle is a thinking tool, a way to surface and examine mental models. It is not a mold for one "right" answer.



These are only sample drawings. Let students present their own ideas and encourage them to weigh the ideas of others. Students are always free to change their drawings as they continue to refine their mental models together.

8. While sharing feedback loops with the whole class, look for elements that appear in more than one loop. Most stories contain overlapping loops. This diagram connects all the previous loops.



Tracing the intertwined loops, notice how kelp plants provide food for shrimp, triggering a biodiversity increase, while also causing sand and silt to build up. The sand and silt loop drives the sea urchin population down, further enabling the kelp to grow. In this diagram, sea urchins and sea otters both have two arrows leading from them, signifying multiple outcomes caused by changes in their populations.

Tracing the story of each loop explains *why* the problem changed over time.

9. Ask students to revisit their original behavior-over-time graphs defining the problem, or have each team choose an element from the circle and sketch how it changed from the time when hunters arrived in the late 1800s to the time when *"The Case of the Two Islands"* was written. Emphasize that the general shape of the graph is important—it cannot be precise because we have no specific data. Share the graphs and ask students to explain how they relate to the feedback loops they have uncovered.

An ecosystem is a delicate balance of many feedback loops. As students uncover these interdependencies, they begin to appreciate the complexity of natural systems.

BRINGING THE LESSON HOME

Give students a chance to bring the lesson full circle. What did they learn? Posing stimulating questions like these will help students ask better questions themselves.

? ***Many things were happening at once in this story. How did the connection circle help you sort them out?***
The mystery of the twin islands often seems baffling at first. Encourage students to reflect on their thinking and on the process of understanding complexity by looking for the interwoven causal loops underlying the problem.

In using connection circles, the thinking process is important – not just the product.

? ***Did you solve the mystery of the twin islands? What effect did sea otters have on the sea urchin population and the balance of the two ecosystems?***
Around Amchitka Island, the sea otter population increased. This caused a decrease in the number of sea urchins. That allowed the kelp forests to grow thickly because they were not being destroyed by sea urchins. The kelp provided habitat for shrimp, which fed many fish. The fish became food for seals and eagles. The increased kelp also sheltered the deposits of sand and silt on the ocean floor, which smothered the bottom dwellers who might try to live there.

In contrast, sea otters had not returned to Shemya Island and a large population of sea urchins lived in the waters there. The sea urchins prevented the growth of kelp, so few shrimp and fish could survive in the inhospitable environment. Bottom dwellers

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Keystone Species in an Ecosystem

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thrived since the sand and silt did not build up over the ocean floor, but these creatures were not desirable food for most fish species. With few fish to attract them, seals and eagles did not colonize Shemya Island and its surrounding waters.

Feedback Loops Tell the Story

Feedback loops explain why the ecosystems were so different. An ecosystem is a delicate balance of feedback loops. Positive loops drive rapid population growth or decline, but nature provides balancing loops to keep positive loops from spiraling out of control. When hunters disturbed the balance by removing the sea otters from the ecosystem, the sea urchin population boomed causing many other changes to the ecosystem.

? *How did hunters affect the islands' ecosystems?*

Fur traders hunted sea otters to the brink of extinction. The decline of the sea otter population allowed sea urchins to proliferate, and the urchins devastated the kelp forests. When kelp forests decrease, many marine animal species are deprived of habitat and their numbers decline as well. Without hunters, sea otters could thrive around Amchitka Island.

? *Author Susan Quinlan calls the sea otter a "keystone species." What does she mean?*

When the sea otter was removed from the Aleutian Islands, the ecosystem collapsed and became barren of many species. Similarly, if the keystone in an arch is removed, all the other stones will fall. Any species that is disproportionately important (i.e., compared to its population) in the maintenance and balance of an ecosystem, and whose removal disrupts or destroys the food web, is thought to be a keystone species. Some scientists believe that only predators can be keystone species but others disagree.

? *What are the keystone species in ecosystems where we live?*

Among animals generally considered to be keystone species are prairie dogs, beavers, freshwater bass, gray wolves, and salmon.

Additional Background Information

Students often generate many good questions that go beyond the original story. Here is some more background information that might be helpful.

? *Why had sea otters come back to Amchitka but not Shemya?*

The story only tells us that a few otters had escaped hunters but "they had not returned yet to Shemya Island." Researchers have proposed several theories to explain the abundance of sea otters on some islands and their scarcity on others. Among the causes hypothesized are coastal currents, algae production, complex factors affecting otter prey, predation on otter pups, and environmental contamination. Interested students can pursue this story further.

? *In the absence of sea urchins, do sea otters eat so much of another species that it becomes depleted?*

Sea otters can deplete their food sources rapidly. As is the case with other species, feedback loops in the environment operate to reduce otter populations when food is scarce and allow it to increase when prey is abundant.

? *What is currently happening to the sea otter population in the Aleutian Islands?*

James Estes and other scientists have continued to study the sea otter population and discovered more threats since 1990. It was estimated that between 150,000 to 300,000 otters lived in the Pacific Coast region before the hunters arrived in the 19th Century. A treaty in 1911 stopped hunting but only about 1,000 otters were left.

In the 1970s, the otter population near Alaska was estimated to have recovered to over 100,000. But in the years leading to the beginning of the 21st Century, they declined again. The culprit this time may be a different species of hunter—killer whales. Killer whales prefer to eat sea lions and seals, but those populations have declined due to reduced fish stocks. Killer whales have turned to sea otters and have reduced their numbers to low levels again. Kelp forests have been noted to be in serious decline by year 2000. Students will see feedback relationships here, too.

Students have used connection circles to define the problem and find the causes of change over time. With practice, they will eventually learn to recognize the feedback loops in the systems around them without the need of this tool.

[1] We have revised this lesson from the version in the earlier edition of *The Shape of Change* (2004) to make our explanation of connection circles more clear. For more information on this lesson and its next steps, also see Lesson 11 in *The Shape of Change, Stocks and Flows* (2007) by Quaden, Ticotsky and Lyneis.

***Connection Circles** continued on page 14*

The Climate Challenge: Our Choices

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2. Explain what parts of bathtub and graphs mean

Hit the Play button and pause around 1970 or so.

First orient learners to what they are seeing. Connect the understanding of the carbon cycle to the bathtub analogy. Key points: Inflow is emissions. Outflow is removals. Water in tub is CO_2 in atmosphere.

Point to the meters on the tub and explain what they represent.

Point to the graphs on the left and show how the lines correspond to the different parts of the bathtub.

3. Explore past behavior and what has been driving it

You should be paused around 1970 or so.

Point to the graph for CO_2 in the atm on the left and ask, "Why is the level of CO_2 in the atmosphere going up?"

Typical answer is "Because we are emitting more CO_2".

Acknowledge this is true but only part of the story. The level of the bathtub is rising because *more is going in than is coming out.* This is a very important point to make early on. Point to the bathtub and the numbers on it to show what is going on.

Here's BIG POINT #1: CO2 in the atmosphere is rising because more is going in than is coming out. Emissions exceed removals.

Hit the Play button again and watch it play up to 2007. Reinforce the point —water in the bathtub is rising because more is going in than is coming out.

4. Offer the goal and explore "Allow increased emissions" future – Learner estimate and model run-

Point to the three buttons for future scenarios and explain them. Give them the challenge of choosing a future that will keep CO_2 in the atmosphere below 450 ppm (not overflow the bathtub) with minimal difficulty.

Ask what will happen if we continue to increase emissions. Don't emphasize this question – it is obvious that the tub will overflow.

Run the scenario. Point out the year (~2038) that the tub overflows. You may want to pause the sim around that time. Watch the overflow.

In the real world, overflowing means passing the goal of 450 ppm. Many scientists believe that passing 450 ppm concentration would mean a triggering of a set of feedback processes that would lead to rapid and severe climate change.

Potential discussion question: What does overflow look like on the ground?

Debrief what happened. Emissions remained above removals so CO_2 in the atmosphere continued to grow.

Do this run quickly and move on to the next few.

5. Explore "Level off" future – Learner estimate and model run

Say that now we will test a future where we level off emissions over the coming decades. No more growth.

Ask, "If you were to go to Times Square in New York City and ask 100 people what would happen to CO_2 in the atmosphere under this scenario, what would 80 of them say?"

Typical response: "They would say that CO_2 in the atmosphere would level off as well. Or actually go down."

Support this idea with the fact that a study at MIT of technically educated graduate students found similar results. 75% of them had a similar estimate.

Next ask them what *they* think would happen.

Run the Sim. Watch. Note that the overflow happens in 2046 so the effort has delayed the problem for 8 years relative to the first run. This is quite good.

Ask why leveling emissions is insufficient.

Answer: Because we did not reduce emissions down to the level of the removals. We didn't reduce the inflow to equal the outflow, which is the only way to stop the bathtub from increasing.

This is BIG POINT #2: To stabilize CO_2 in the atmosphere, emissions will need to equal removals.

6. Explore "Reduce emissions" future – model run

Explain what will happen in this run. Don't emphasize the learner estimate this time.

Run the future and watch emissions fall to meet removals.

Make BIG POINT #3: To stabilize CO_2 in the atmosphere by getting emissions to equal removals, it will be necessary to make significant reductions (over 50%) in emissions.

***Climate** continued on page 10*

The Climate Challenge: Our Choices

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7. Revisit learnings

You may want to recap the BIG POINTS.

- CO_2 in the atmosphere is rising because more is going in than is coming out. Emissions exceed removals.
- To stabilize CO_2 in the atmosphere, emissions will need to equal removals.
- To stabilize CO_2 in the atmosphere by getting emissions to equal removals, it will be necessary to make significant reductions (over 50%) in emissions.

Discussion topics:

- If most people think that leveling emissions will level CO_2 in the atm but this is not the case, what would this lead to? (Apathy about reducing emissions and subsequent exacerbation of the problem)
- What does a significant reduction of emissions look like in the real world?

Frequently Asked Questions

(Note –Michael Tempel and Susan Randel of Schlumberger/SEED contributed significant sections of the FAQs)

Who made this Sim?
This simulation was conceptualized and built through a collaboration between Schlumberger/SEED, The Sustainability Institute, the Society for Organizational Learning, the System Dynamics Group at MIT, and the MaMaMedia Consulting Group. The numbers that drive the graphs and the bathtub animation were calculated in a system dynamics model built by Dr. Thomas Fiddaman. Schlumberger Ltd. holds the copyright.

Why 450 ppm as a goal?
Already there is much more CO_2 in the atmosphere than at any time in the past 425,000 years. In 2007 the concentration of CO_2 in the atmosphere was approximately 380 parts per million (ppm). Every year human activities add to that. Some scientists and economists in the climate science world such as James Hansen (note) have identified a concentration of 450 ppm as a maximum goal for CO_2 that may avoid the most significant damage to the Earth's ecosystems and economies. There is a great deal of uncertainty about the severity of the effects associated with this or any other target level for CO_2. We have chosen to use it for this simulation, but we could have set it higher or lower. As you play with the simulation consider how the three scenarios would play out if the bathtub overflowed at a level other than 450 ppm.

How is** CO_2 **in the atmosphere like a bathtub?
The principle at work here is stock and flow. A "stock" is something that accumulates, in this case CO_2 in the atmosphere, represented by the water. The bathtub stands in for the Earth's atmosphere. Water (CO_2) enters the bathtub (atmosphere) from the spigot above and leaves the bathtub through the drain below. This is the "flow," a representation of how much goes in and how much goes out.

For the past 425,000 years the amount of CO_2 in the atmosphere has fluctuated between 175 ppm and 300 ppm. The inflow (the amount of CO_2 going into the atmosphere) and outflow (the amount of CO_2 removed from the atmosphere) were sufficiently in balance during this period of time to keep the CO_2 level within that range. In the past few decades the inflow has increased dramatically. The flows are now out of balance. More and more CO_2 is entering the atmosphere, but not nearly as much is being removed. Thus, CO_2 increasingly accumulates in the atmosphere. The amount now stands at a concentration of 380 ppm. In our simulation, the bathtub can overflow if the amount of CO_2 in the atmosphere increases to the point of significantly altering the climate.

What are the three future options we have in the Sim?
• *Allow Increasing CO_2 Emissions*
One scenario is to allow human emissions of CO_2 to increase at roughly current levels. This means that governments around the world would not regulate CO_2 emissions, and businesses and individuals would not take any special action to reduce CO_2 emissions. Everything would continue on as it has been going. This "business as usual" or "status quo" approach asks: What if we did nothing?

The numbers used in this scenario were the "business as usual" estimates of the Intergovernmental Panel on Climate Change (IPCC), the international group dedicated to studying this issue. In this scenario, removals increase naturally, but are never able to keep up with the increase. By the year 2045 the levels would reach 450 ppm. This amount would cause significant changes in the atmosphere, and global warming would cause dramatic changes to the environment.

In our climate simulation, the bathtub would overflow by 2045, and we would experience even more significant climate change. This future is what the IPCC scientists expect will happen if we make no major changes to avert climate change.

• *Level Off CO_2 Emissions*
Another option is to gradually stop

the increase of human-caused emissions of CO_2 in the decades following 2007. This scenario is based loosely on the Kyoto Protocol, an international treaty to reduce CO_2 emissions. The treaty was negotiated by the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 and went into effect in 2005. More than 150 nations were involved in creating the Kyoto Protocol, and 84 countries signed the agreement. However, the agreement also needed to be ratified by each country, and not all who signed the protocol ratified or approved it at home. The leading industrialized countries that have ratified it include Russia, Japan, and the members of the European Union. Other countries have since joined the agreement, bringing the total to more than 165. The United States and Australia are among the industrialized countries that signed but did not ratify the Kyoto Protocol.

The countries that did agree to follow the protocol produce about 60% of the world's greenhouse gases. The agreement is for industrialized countries to reduce greenhouse gas emissions to 5.2% lower than 1990 levels by 2012. This would roughly level off CO_2 emissions. But is stabilizing emissions enough to prevent CO_2 levels from going above 450 ppm?

• *Reduce CO_2 Emissions*

What if all the governments in the world agreed to significantly reduce CO_2 emissions? A plan like this has been proposed by former U.S. vice president Al Gore. Climatologist David Stern has proposed something similar. This scenario calls for reducing emissions of CO_2 by 58% of the 2007 level by 2070. What would happen to our bathtub? Would it still overflow?

Questions about CO2 and Climate Change

What are CO_2 emissions?

Carbon dioxide (***CO_2***) is a gas that makes up a tiny fraction of the Earth's atmosphere. It occurs naturally, mostly as a result of breathing, of decay, from the burning of wood and the release of ***CO_2*** from the oceans. ***CO_2*** emissions also result from the burning of fossil fuels and other human activities. It is this human-generated ***CO_2*** that we are showing in our simulation.

What are CO_2 removals?

Carbon sinks remove carbon from the atmosphere. The main carbon sinks responsible for removals are photosynthesis and absorption by the oceans.

The oceans are both a carbon sink and a source of ***CO_2***. There is an ongoing exchange of ***CO_2*** between the atmosphere and the oceans. The balance depends upon factors including water temperature and the concentrations of ***CO_2*** in both the oceans and the atmosphere.

For hundreds of thousands of years, emissions and removals remained roughly in balance, with the concentration of ***CO_2*** in the atmosphere varying between 180 and 300 parts per million (ppm). This was true until humans began to burn fossil fuels during the Industrial Revolution. These additional ***CO_2*** emissions are the problem. Currently much more ***CO_2*** is being released than can be taken up by plants or absorbed by the ocean. The concentration of ***CO_2*** in the atmosphere is now 380 ppm and rising.

Why do removals seem to follow emissions?

Carbon dioxide flows between the atmosphere, biosphere, and oceans in order to maintain a balanced distribution. When the concentration of CO_2 in the atmosphere increases, two things happen:

- "***CO_2*** fertilization" occurs. Plants use more ***CO_2*** for photosynthesis, growing more leaves and woody material.
- The surface ocean—mixed by wind-driven waves—quickly absorbs ***CO_2***, which then diffuses more gradually into the deep ocean.

Both processes have limits. The oceans can only absorb so much ***CO_2*** before releasing as much ***CO_2*** back to the atmosphere as was taken up. For plants, the limitations on growth from water and other nutrients become important. This is called "sink saturation."

In the "Allow Increased Emissions" future, removals increase because the rapidly-growing concentration of ***CO_2*** in the atmosphere continues to drive uptake. Part of the excess ***CO_2*** is absorbed by plants and the oceans. In the "Reduce ***CO_2*** Emissions" future, removals fall because the excess of CO_2 in the atmosphere above that in the biosphere and oceans is not so great.

What's the connection between CO_2 and climate change?

We know that ***CO_2*** absorbs heat from the Sun and releases it into the atmosphere. Going back millions of years, when the concentration of ***CO_2*** was higher, the Earth was warmer. Eventually ***CO_2*** concentration dropped and the world became cooler. Since the 1740's ***CO_2*** concentration has increased significantly, and the average temperature on Earth has also increased.

Why does the CO_2 level in the atmosphere continue to rise even when emissions are leveled off?

This scenario corresponds to clicking the middle button in our simulation:

Climate *continued on page 12*

The Climate Challenge: Our Choices

continued from page 11

"LEVEL OFF CO_2 EMISSIONS." After about 2045 emissions are no longer increasing. At that point removals are also level from year to year. But since emissions are greater than removals, each year more CO_2 goes into the atmosphere than is removed. So the amount of CO_2 in the atmosphere continues to rise.

It's like a bus traveling through the city with people getting on and off. Let's say that at one stop 5 people get on the bus and 3 get off. At the next stop the same thing happens: 5 people get on and 3 get off. If this pattern continues the bus will get very crowded. The number of people getting on the bus is level: 5 at each stop. But since only three people get off there is an increase of 2 people each time the bus stops. In order to keep the crowding from getting worse, the same number of people have to get off the bus as get on. And to reduce the crowding, more people have to get off than get on.

In order to keep the concentration of CO_2 in the atmosphere at a given level, say 450 ppm, emissions and removals have to be equal. In order to reduce the concentration of CO_2 in the atmosphere, removals have to be greater than emissions.

Where can I learn more?

The Sim is on the web at:
http://www.seed.slb.com/en/scictr/watch/climate_change/challenge.htm

The contact at Sustainability Institute is:
Drew Jones
828-236-0884
apjones@sustainer.org
www.sustainabilityinstitute.org

To understand the public understanding of climate dynamics, read the paper by John Sterman and Linda Booth Sweeney. It also explains climate dynamics with a bathtub perspective quite clearly.

http://web.mit.edu/jsterman/www/StermanSweeney.pdf

…that school in Tucson

A longitudinal study of systems thinking in K–12 education

The CLE is excited to announce a new DVD and accompanying booklet which highlight the power of systems thinking and system dynamics.

Thirteen years ago, middle school students and their faculty in Tucson, AZ, pioneered a revolutionary new approach to learning—using Systems Thinking tools to engage in collaborative, real-world problem solving that honed their critical thinking skills. We have the rare opportunity to revisit some of them thirteen years later and hear how this learner-centered approach transformed their lives. The excitement they felt, the confidence they developed, and the fostered habits of mind are all still evident in their maturation into young adults with the skills and motivation to be leaders in today's complex world. In our increasingly fast-paced and interconnected world, the citizens of tomorrow (our students today) will need these skills to cope with dynamic complexity. Systems Thinking helps students and adults sort out that complexity and make decisions based on a powerful approach to collaborative problem-solving. The accompanying booklet defines and explains the tools of Systems Thinking and its parent discipline, system dynamics; describes how it is working in various settings; and leads school boards, administrators, and teachers to the next steps in making this exciting innovation a reality in schools across the country.

Written, produced and directed by James Morrison

Accompanying booklet written by the Creative Learning Exchange

Funded by W.T. Kellogg Foundation

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www.clexchange.org

The Catalina Foothills School District has been using Systems Thinking in their classrooms for over fifteen years. This video, and the Systems Thinking work at Catalina Foothills School District, would not have been possible without the generosity of Faith and Jim Waters and the Waters Foundation.

ST/DM Conference for K-12 Education, June 28-30, 2008 Draft Program

Friday, June 27

7:00-9:00 pm Registration

Saturday, June 28

8:30-10:00 Registration/Continental Breakfast

10:00-12:00 Introductions/Welcome/Keynote: Peter Senge: ***Educating for Systems Citizenship***

12:00-1:30 Lunch

1:30-5:00 Session I Workshops

- Introductory Systems Thinking (Based on The Shape of Change Books): *Rob Quaden and Alan Ticotsky*
- Systems Games from The Systems Thinking Playbook: *Dennis Meadows and Linda Booth Sweeney* (2 hours)
- Developing Teacher Leaders: Using Systems Tools in School-Based Action Research Projects: *Tim Lucas*
- Beginning System Dynamics Modeling: *Diana Fisher*
- The Commons: Sustainability and Systems Thinking: *Jaimie Cloud*
- Converting Simple SD Models Into Games: Dennis Meadows (1 hour)

6:30-7:30 Dinner

7:30 After-dinner reception: Chat with system dynamics teachers, including Jay Forrester, George Richardson, Dennis Meadows.

Sunday, June 29

9:00-10:30 Keynote: Elaine Johnson: ***Brain-Based Learning. How does what we know about the brain inform us about students' learning?***

11:00-12:00 How do we integrate brain-based learning into teaching/utilizing systems thinking and system dynamics in the classroom and organization? Small group discussion.

12:00-1:30 Lunch

1:30-3:00 Session II

- The Exponential Factor: Tip the Dynamics in Your Favor to Improve Schools: *Tracy Benson*
- Using The System Dynamics Process To Create Classroom Lessons: *Diana Fisher*
- Inquiring Minds Want To Know: *Sheri Marlin*
- Utilizing ST/SD to Bring Inductive Reasoning to Standardized Curricula (especially Biology): *Steven Roderick*
- Teaching Personal Finance Using System Dynamics: *John Heinbokel, Jeff Potash*
- Systems Thinking and the Internet: We've Only Just Begun!: *Anne LaVigne, Mary Scheetz, Joan Yates*
- A Case Study on International Collaboration with China: *Rob Skiff, Piper Stover*

3:30-5:00 Session III

- An Effective Planning Tool for English Composition Writing, First through Fifth Grades: *Ng Kok Leong*
- A Workshop in SD Notetaking Across the Curriculum: *David Wheat*
- Systems and Water Science Pilot Program for High School Students: *Rudy Renya, Elizabeth Pate, Ben Jurewicz*
- Designing Democratic Communities for Trust in Learning: *Lisa Kensler*
- Let NCLB=New Curricula Leverages Brainpower (through Systems Thinking): *Andrea Davidson, Joan Yates*
- Using the System Dynamics Process on News Articles in the Classroom: *Hongyan Zhang*
- Teaching Physics in High School Using a Semiquantitative Modeling Environment: *Cristiane de Olivera, Fabio Sampaio*
- Advanced System Dynamics Modeling (previous experience required): *George Richardson*

6:00 Pre-dinner gathering with Poster Session

6:30-7:30 Dinner

7:30-9:00

- Showing of DVD ***...that school in Tucson***, a longitudinal study about systems thinking in the classroom.
- Interest group meetings

Monday, June 30

8:30-10:00 Session IV

- System Dynamics with Young Children, a View from the Netherlands: *Jan Bisschops*
- Collaborative Systems Modeling Teaching the Principles of Ecological Economics: *Ida Kubiszewski, Roelof Boumans*
- Informing Educational Policy Using System Dynamics: *Ralph Brauer, John Heinbokel, Jeff Potash*
- Cross-Culturally Exploring the Potential for Systems Thinking as an Instructional Foundation: *Rob Quaden, Larry Weathers, Sami Kuo, Diana Hou*
- The Value of Model-Based Simulators for Teaching ST Principles and Subject Matter with Dynamic Content: *Gary Hirsch*
- Systems Concepts and the Design of a Household or Classroom Marine Aquarium: *Alice Squires*
- Thinking about Systems: A research review of student and teacher conceptions of living systems: *Linda Booth Sweeney*

10:00-11:30 Keynote: George Richardson: ***On the Foundation of Systems Thinking and System Dynamics***

Special Educators Workshop in NH August 11-15, 2008

"Dynamic Modeling with STELLA" will build skills to integrate dynamic modeling into your classroom

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FMI: http://www.iseesystems.com/store/training/SystemsApproachEdu-SupportCurric.aspx

Keystone Species in an Ecosystem

continued from page 8

[2] "The Case of the Twin Islands" is a chapter from *The Case of the Mummified Pigs and Other Mysteries of Nature*, by Susan E. Quinlan, illustrated by Jennifer Owens Dewey, published by Caroline House, Boyds Mills Press, Inc., 1995. For your convenience, the chapter is reprinted with permission on page 133 in *The Shape of Change*. We urge you to get the book and use connection circles to explore its many other intriguing stories.

The latest edition of The Shape of Change, presenting eleven attractively illustrated and formatted classroom activities, is available from The Creative Learning Exchange, Acton, Massachusetts 01720
http://www.clexchange.org
email: milleras@clexchange.org.

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If you would like to invest in our effort at *The Creative Learning Exchange*, your contribution would be appreciated. You may donate any amount you wish; perhaps $50.00 is a reasonable amount for a year. All contributions are tax-deductible.

Enclosed is __________________ to *The Creative Learning Exchange* to help invest in the future of K-12 systems education.

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