SUSTAINABLE TOMORROW

A Teacher's Guidebook for Applying Systems Thinking to Environmental Education Curricula

By Colleen F. Ponto, Ed. D. and Nalani P. Linder, M.A.

Sponsors
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PREFACE

Welcome! This resource is the next generation of a product that was created by the Association of Fish and Wildlife Agencies in the early 2000's. The Education Working Group of the Education, Outreach, and Diversity Committee received a multi-state grant in 2020 to update this resource and several others from the North American Conservation Education Strategy toolkit and make it relevant to educators today.

This resource is an update to the work of generations of wildlife educators from across the country. We honor their work by updating, not replacing, this incredibly useful resource that can be used by conservation educators and classroom teachers across North America. A sincere thank you to everyone who created the original resource as well as DJ Case & Associates who brought this resource into the current era of education.

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Dear Educator,

Given the complex social, economic, and environmental concerns of our time, the need for environmental and sustainability education has never been greater. To meet this growing need, many educators the world over are learning how to integrate systems thinking and sustainability education into their teaching of more traditional subject areas such as science, math, social studies, language, and the arts so that our children learn the concepts, understand the principles, develop the habits, and master the skills required to make sense of and thrive in our complex and interdependent world. Such is the aim of this guidebook.

Our hope is that in using this guidebook, teachers gain competence and confidence to begin experimenting with integrating systems thinking into their instruction. Like learning to read, systems thinking literacy is only achieved through ongoing experimentation and practice. We recommend learning and teaching systems thinking with others and using the growing number of online resources available to keep practicing (see Systems Thinking References and Resources in Appendix A). We also encourage you to form a community of practice in your schools focused on developing systems thinking skills.

We welcome your feedback on the usefulness of this guidebook as well as any suggestions for improvement.

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Why this Guidebook was Created

Over the last several years, the understanding of 'systems' has increasingly become a core concept found within state science standards. This guidebook was created to supplement the high quality curricula for K-12 environmental science education with an applied guide to understanding, using, and developing skills in systems thinking when considering environmental science topics. Built upon current systems thinking research and pedagogy, this guidebook is intended to help environmental educators further understand systems thinking tools and concepts, as well as to offer easy-to-implement ways they can weave systems thinking into their existing environmental education lessons.

Research has shown that once students begin to see interconnections and develop systems thinking skills, their systemic perspective crosses over into other areas of study. They begin to see relationships between ideas taught in various subject areas—independent of the degree of curricula integration.

We hope that the tools and concepts of systems thinking described within this guidebook will be used and internalized by students so they would naturally begin to apply the same concepts into other areas of study— seeing systems beyond the science classroom and into areas of social studies, math, literature, and other subjects.

How to use this Guidebook

This guidebook was designed for teachers and learners of systems thinking. Detailed descriptions of how to use systems concepts and tools are provided. You will want to read the introductory material carefully and practice with the examples given.

Once you become familiar with the tools and concepts, you may be interested in adapting your own classroom lessons with systems thinking. Tips and guidelines are provided in How to Select Learning Activities that Can Be Enhanced by Systems Thinking on page 24. Two lessons from Project WILD Aquatic (2008) and Project WET (2000) are included as examples of how existing environmental education lessons can be adapted.

Linking to Standards

The activities within Sustainable Tomorrow address and often exceed the learning standards for Systems in the subject areas of Science and Environmental and Sustainability Education. In this guidebook, students learn a six-step process of systems analysis:

1. Tell the story
2. Name the variables
3. Determine the system boundaries
4. Sketch the trends
5. Make the system visible
6. Look for leverage for sustainability

Processes	NGSS	NCSSS	Notes
Tell the story	H.S. Engineering Design	Theme 1: Culture Theme 2: Time, Continuity, and Change	
Name the variables	H.S. Engineering Design	Theme 3: People, Places, and Environments	
Determine the system boundaries	H.S. Engineering Design	Theme 3: People, Places, and Environments	
Sketch the trends	H.S. Engineering Design	Theme 2: Time, Continuity, and Change Theme 3: People, Places, and Environments	
Make the system visible	H.S. Engineering Design	Theme 5: Individuals, Groups, and Institutions Theme 8: Science, Technology, and Society	
Look for leverage for sustainability	H.S. Engineering Design	Theme 8: Science, Technology, and Society	

Students who demonstrate understanding can: HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education:*

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1) Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4) Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2) Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	ETS1.A: Defining and Delimiting Engineering Problems Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) ETS1.B: Developing Possible Solutions When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4) ETS1.C: Optimizing the Design Solution Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	Systems and System Models Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-ETS1-4) ------------------------------ Connections to Engineering, Technology, and Applications of Science Influence of Science, Engineering, and Technology on Society and the Natural World New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1) (HS-ETS1-3)

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:

Physical Science: HS-PS2-3, HS-PS3-3

Connections to HS-ETS1.B: Developing Possible Solutions Problems include:

Earth and Space Science: HS-ESS3-2, HS-ESS3-4 Life Science: HS-LS2-7, HS-LS4-6

Connections to MS-ETS1.C: Optimizing the Design Solution include:

Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-levels:

MS.ETS1.A (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4); **MS.ETS1.B** (HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4); **MS.ETS1.C** (HS-ETS1-2),(HS-ETS1-4)

Common Core State Standards Connections:

ELA/Literacy -

RST.11-12.7
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-ETS1-1),(HS-ETS1-3)

RST.11-12.8
Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-1),(HS-ETS1-3)

RST.11-12.9
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-ETS1-1),(HS-ETS1-3)

Mathematics -

MP.2
Reason abstractly and quantitatively. (HS-ETS1-1),(HS-ETS1-3),(HS-ETS1-4)

MP.4
Model with mathematics. (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4)

INTRODUCTION TO SYSTEMS THINKING IN ENVIRONMENTAL EDUCATION

What is a system?

The definition of a system varies in the science, environmental, and sustainability literature. The definition that informed this guidebook is:

A system is two or more parts interacting to function as a whole within some boundary. The elements and processes of a system interact and affect one another, often in ways we cannot see. In systems, the relationship among the parts matters - if elements or parts of a system are added or taken away, the system's behavior changes.

What is Systems Thinking?

Systems thinking looks at the whole system rather than focusing on a single part or set of parts to better understand complex phenomena. Unlike some other modes of analysis, systems thinking looks beyond simple cause and effect within a given situation; it goes deeper—considering concepts such as unintended consequences, circular cause and effect (which yield balancing and reinforcing dynamics within a system); time delays, and boundaries of a system. These sophisticated concepts enable learners to gain new insights and give greater access to long-term thinking, which is essential to promoting sustainability of all kinds.

Why Systems Thinking in Environmental Education?

Understanding the interdependencies within our natural systems is the key that unlocks deeper awareness about how we are connected to our environment. The tools and habits of systems thinking help us identify when our or others' short-term solutions may have dangerous long-term consequences.

It can help us carefully contemplate our assumptions and ways of thinking, enabling us to perform a rigorous analysis and explore a deeper personal reflection. These are all essential skills to equip 21st-century learners to deal with the social, economic, political, and environmental complexities they are inheriting - much of which results from less-than-systemic thinking.

With our environmental systems in peril, there is no better time than now to equip learners of all ages with the thinking tools necessary to understand complex interdependencies within our natural world. When one can more fully understand systems concepts such as multiple interdependencies and unintended consequences, one can begin to see the role we can play in creating a sustainable future.

Students in the U.S. have traditionally been taught through a linear and mechanistic worldview. Although this worldview has some benefits, it has not prepared our students with the perspectives and skills needed to address the complex environmental issues facing us today effectively. Experience has shown that students can embrace this worldview and grasp systems concepts as early as kindergarten. Additionally, students in middle and high school can use more sophisticated systems concepts and tools such as systems analysis and computer modeling to make sense of highly complex systems. We believe that these skills are essential for global citizenship in the 21st century.

Systems Thinking Concepts

There are a number of essential concepts in systems thinking. Many of these are familiar terms in other fields but have a particular meaning when discussing complex systems, such as feedback, variables, and delays. While few of the concepts are unique to systems thinking, the entire complement of terms and ideas constitute a wholly unique and, we believe, under-utilized way of viewing the world.

Following is a list of some of the most commonly used terms and concepts within systems thinking. An alphabetical listing of these concepts can be found in Appendix D.

Variable

Any changed or changing factor used to test a hypothesis or prediction in an investigation that could affect the results. In systems analysis, variables are nouns or noun phrases that go up or down over time. For example, the number of trees planted, wolves in Yellowstone, or parts per million of CO2 in the atmosphere.

A systems thinker asks:

- What are the key variables in this story?
- How does a change in this variable influence other variables in this story?

Perspective

A particular view or way of looking at a situation. In systems analysis, multiple perspectives help us better understand complex issues.

A systems thinker asks:

- What other perspectives might help us more fully understand this story?

Feedback

When information about the output of a system is fed back around to the input of the system. Feedback is any reciprocal flow of influence and is the basic building block of systems thinking. In system dynamics, feedback is also known as circular causality and is often depicted graphically as causal loop diagrams.

A systems thinker asks:

- Where is there feedback in this system?

Time Horizon

A length of time under consideration; the units of a time horizon can vary and be as short as seconds or as long as centuries. A systems thinker chooses the time horizon when analyzing a story.

A systems thinker asks:
- What time horizon is long enough to see patterns in behavior?

Delay

The amount of time between an action and its consequence.

Often people don't wait long enough to see the long-term consequences of their actions. In systems analysis, awareness of delays is critical to understanding the dynamics of the system.

A systems thinker asks:
- Where are there delays in this feedback loop?
- How do these delays affect our behavior?

Cause & Effect Relationship

An essential aspect of systems analysis. Whether or not 'A' causes an effect on 'B' is a focus of inquiry to test as either a fact or mental model (see below).

Circular Causality

(See Feedback)

Boundary

The line that separates one area from another. A systems thinker creates boundaries to facilitate systems analysis but remembers that boundaries are arbitrary.

A systems thinker asks:

- Is the boundary we set around this system appropriate for our analysis?

Stock

A quantity that accumulates over time. A stock increases by a flow in (inflow/input) and decreases by a flow out (out-flow/output). For example, the number of trees in a forest is a stock, and trees planted is an inflow and trees harvested is an outflow. Stocks can only be changed by their flows. In systems analysis a stock/flow diagram helps illustrate how a stock changes over time. (See Flow).

A systems thinker asks:

- What variables in this story are stocks?

Flow

A material or information that enters or leaves a stock at some rate over a period of time. (See Stock).

A systems thinker asks:

- What variables in this story are flows that influence the stocks?

Event

Something that happens; a single occurrence perceived through the senses. An event that repeats over time is called a pattern. (See Pattern).

A systems thinker asks:

- What happened?
- What did we see, feel, smell, hear, and/or taste?

Pattern

An event that repeats over time. (See Event).

A systems thinker asks:
- What keeps happening over time?
- What recurring events are we noticing?

Structure

The way in which the parts of a system are organized and relate to each other. Sometimes the structure of a system can be seen and sometimes it cannot be seen. How desks in a classroom are arranged is an example of a structure we can see. The rules and laws that are in place in our schools and communities are examples of structures that we cannot see. The structure of a system drives its behavior.

A systems thinker asks:
- What structures are in place in this system that may be determining the behaviors we see?

Mental Model

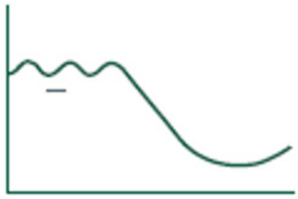
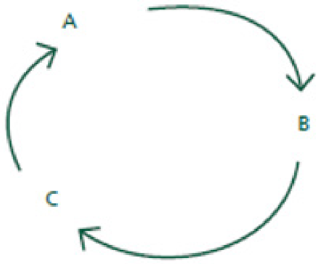
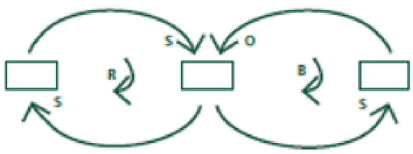
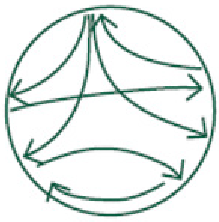
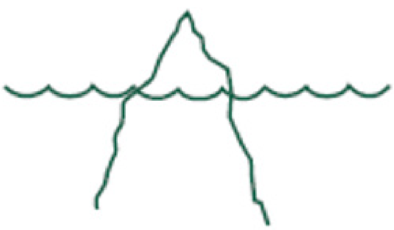
An internal picture about how we view the world. Mental models are often influenced by one's culture. Human behavior and systemic structures are informed by mental models. The view that 'natural resources are unlimited' is an example of a mental model.

A systems thinker asks:
- What underlying beliefs or assumptions are at play in this story?

Leverage Point

A place in a system where making a small change can result in a large improvement in the whole system.

A systems thinker asks:
- Where in this system could we make small shifts that would make a big difference?

	<u>Behavior Over Time Graph</u> A visual tool showing how one or more variables in a system change over time. (See Variable). A systems thinker asks: • How are the key variables in this story changing over time?
	<u>Causal Loop/Feedback Loop</u> A visual tool which shows how two or more variables influence each other. For example, variable A affects B, B affects C, and in turn, C affects A. A systems thinker asks: • How do these variables influence one another? • Is this a balancing or reinforcing feedback loop?
	<u>Causal Loop Diagram</u> A drawing that shows the relationships among one or more feedback loops relevant to a story being analyzed. (See Causal Loop/Feedback Loop). The influence of the feedback will always create either a reinforcing or balancing dynamic in the system. (See Causal Loop/Feedback Loop and page 13 for instructions on how to label a causal loop diagram). A systems thinker asks: • What feedback loops are important to include in this causal loop diagram? How do these loops affect one another? • Where are the delays that affect the dynamics of this system?
	<u>Connection Circle</u> A visual tool which shows the relationships among variables in a story. A systems thinker asks: • What are the key variables in this story and what are the cause and effect relationships between the variables?
	<u>Iceberg Model</u> A visual tool that illustrates how events or patterns are likely caused by underlying structures in a system and people's mental models. (See Event, Pattern, Structure, and Mental Model). A systems thinker asks: • What system structures and mental models are driving the behavior (events and patterns) that we see?

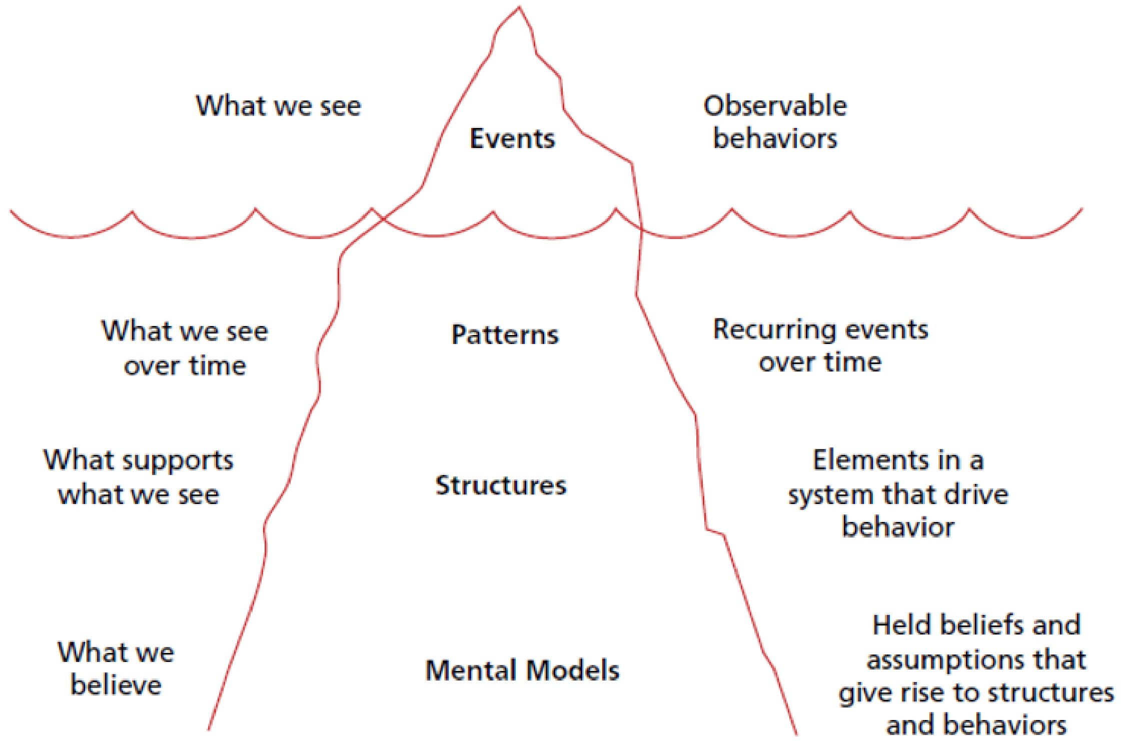


Figure 1. Iceberg Model

	<u>Stock/Flow Diagram</u> A drawing which shows a stock and its inflows and outflows. A stock/flow diagram helps us see what influences the increase or decrease of a stock. For example, whale population is a stock determined by whale births (inflow) and whale deaths (outflow). A bathtub with its faucet and drain is the common metaphor used to explain stocks that increase or decrease, and rates of flow in and out of a stock. (See Stock and Flow). A systems thinker asks: • How is the stock changing over time as determined by the inflows and outflows? What variables impact inflows and outflows? • What steps can we take to raise or lower the stock to keep it in an acceptable range?

Systems Thinking Skills

> S.T.O.P. = Systems Thinking Opens Possibilities
>
> Why S.T.O.P.?
>
> When confronted with a complex issue, a systems thinker stops and takes time to explore the system more deeply to open possibilities for long-term sustainable solutions.
>
> How is a systems analysis different than other scientific analyses?
>
> The 6-step process for systems analysis integrates inquiry, critical thinking, graphic organizing, and reflection skills, all of which are important skills in scientific analysis. To these, we add the systems perspective. The focus is on the dynamics that occur because of the feedback relationships between the variables in a system.

A great way to build systems thinking skills is to practice looking at issues through a systems analysis. The steps for the analysis presented here use all of the essential systems thinking skills to help students deepen their understanding of an issue.

> S.T.O.P. for Systems Understanding
>
> Systems Analysis in Six Steps
>
> 1. Tell the story
> 2. Name the variables
> 3. Determine the system boundaries
> 4. Sketch the trends
>   - Behavior over time graphs
> 5. Make the system visible
>   - Connection circles
>   - Causal loop diagrams
>   - Stock/flow diagrams
> 6. Look for leverage for sustainability
>   - Iceberg Model

Here is an example of how you might use a systems analysis to better understand an issue about the predator/prey relationship of foxes and rabbits on a prairie.

Example and Practice

1. Tell the story

Systems thinking begins with a story—an account of some particular event or events. Tell the story you want to analyze with one or more people. Use your own words, and encourage listeners to ask questions to clarify their own understanding. Everyone should be clear about what the story is about and the scope or boundary of the story. Here is a story about predators and prey:

There is a prairie ecosystem inhabited by foxes and rabbits. Foxes eat rabbits, of course, and when rabbits are abundant the number of foxes increases, as well.

Inquiry: Ask questions to more fully flesh out the system.

For example, what other influences are there on the number of foxes and rabbits (farmers, weather, available food sources, etc.)?

2. Name the variables

In systems thinking, variables are noun or noun phrases that go up or down over time.

What are the key variables in the story about the prairie ecosystem?
• Number of rabbits
• Number of foxes

3. Determine the system boundaries

Because system boundaries are arbitrary, we get to choose what they are. Boundaries help us with the scope of our inquiry.

In our prairie story what geographic boundaries are we assuming for the purposes of this systems analysis?

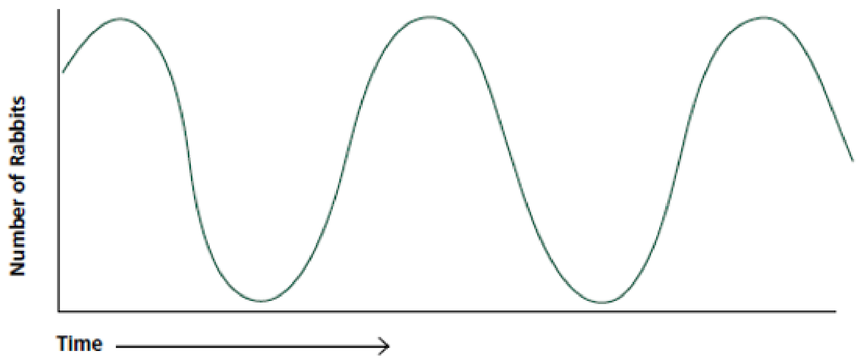
Tips for Naming Variables

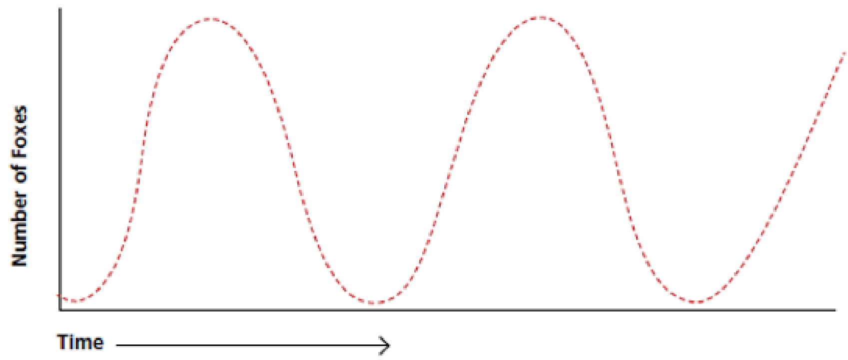
When naming variables, using precise language is important. A well-named variable includes phrases such as "number of," "level of," or "amount of." In this systems analysis, we are focusing on the number of rabbits and the number of foxes. It is also helpful to describe the nouns in neutral or positive terms. For example, "number of foxes" is better than "less foxes."

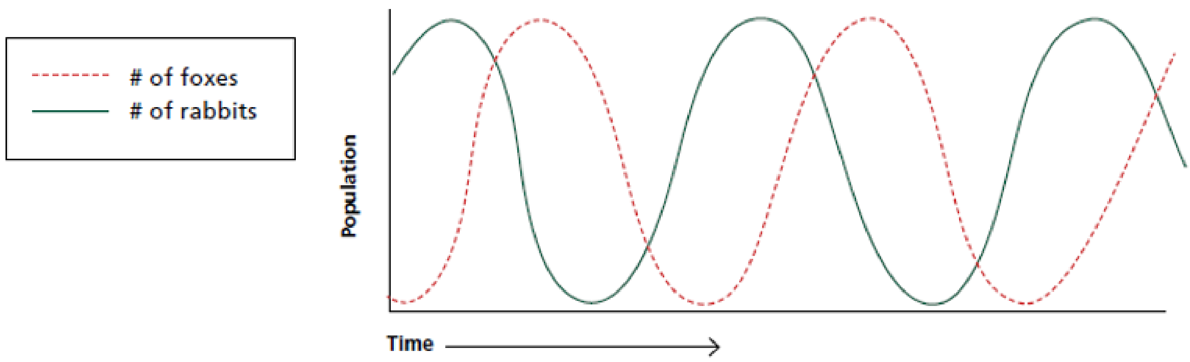
4. Sketch the trends

One of the basic systems thinking tools is a behavior over time graph, a visual tool which helps us see trends—how variables change over time. Sometimes, sketching more than one variable on the same behavior over time graph can help us see a relationship between the variables.

How are the key variables in the prairie ecosystem story changing over time? How does the rabbit population (number of rabbits) change over time? How does the fox population (number of foxes) change over time?







5. Make the system visible

There are many graphic tools that can be used to better understand a story. Here are three that help systems thinkers see the dynamics of a system by looking at the relationships among key variables: connection circles, causal loop diagrams, and stock/flow diagrams.

Which graphic tool should I use?

Is it necessary to use all three graphics for each systems analysis? Not necessarily. Each tool helps with specific learning insights (see reference chart).

	Connection Circle	Causal Loop Diagram	Stock / Flow Diagram
To practice identifying key variables and how they relate to each other	■		
To identify the feedback loops in a system	■	■	■
To consider how feedback makes a variable (stock) increase, decrease, or oscillate over time		■	■
To understand why certain variables (stocks) change over time while accounting for factors such as rates of change			■
To create a preliminary diagram as a precursor to a computer simulation*			■

**How to build and use computer simulation models goes beyond the scope of this text. An excellent online resource for learning more about computer simulation modeling can be found at: http://www.clexchange.org/gettingstarted/msst.asp*

You may find it useful to make the system visible in all three ways to both build your systems thinking experience and develop a richer understanding of the same issue through multiple graphics.

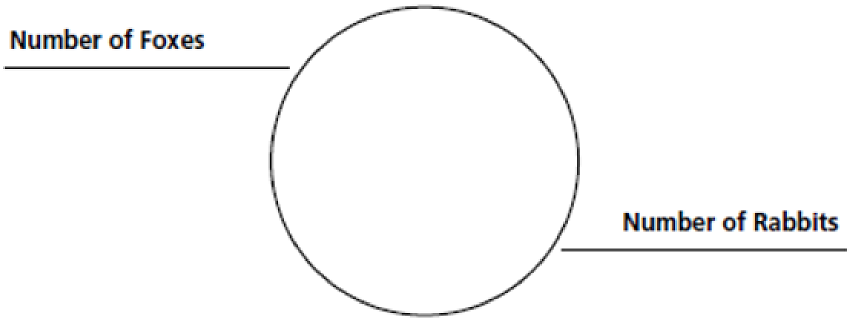
Let's start with the most basic of the three tools covered here—connection circles. A connection circle is a basic visual tool that shows the relationships among variables in a story. It is often used as a beginning step before creating a causal loop diagram.

To draw a connection circle, ask yourself:

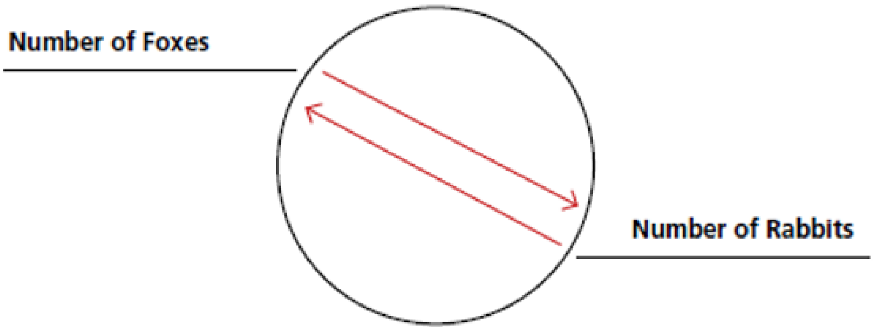
- What are the elements in the story (the variables) that are changing over time?
- Are they connected to each other?

Once you identify the variables, write them anywhere around the outside of a circle.

In complex stories there can be several variables. Our story about foxes and rabbits contains only two: "Number of foxes" and "number of rabbits." For an example of a connection circle that contains multiple variables, see page 36.



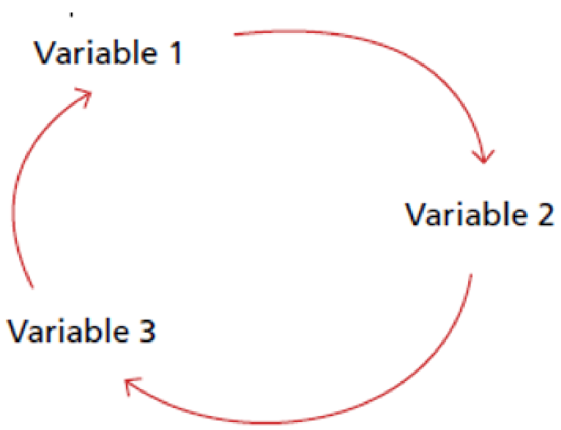
Next, consider if and how the variables are connected to each other, and draw an arrow wherever you see a cause-and-effect relationship. Make sure you can explain your thinking.



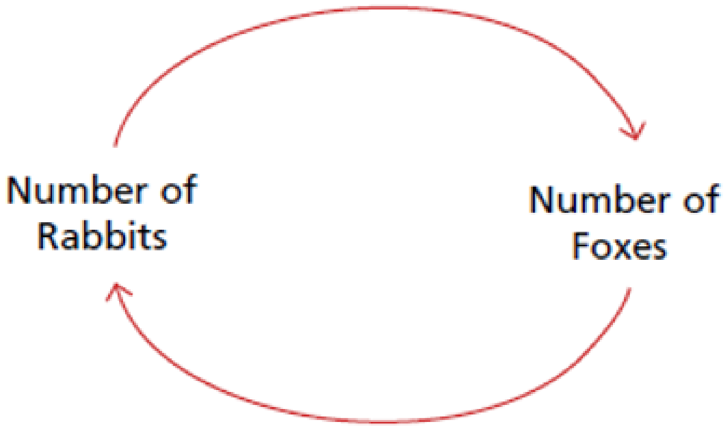
As the number of rabbits increases over time, the number of foxes increases. As the number of foxes decreases over time, the number of rabbits decreases.

Once you have determined connections through a connection circle, you can move to a causal loop diagram, which shows the relationships among one or more feedback loops relevant to the story being analyzed. To draw a causal loop diagram, ask yourself: Which variables in the story make a cause-and-effect loop? (Note that there may be more than two variables in a loop, and there may be more than one loop.)

Then, for each loop write the variables and draw a curved arrow to indicate cause and effect, like this:



In our story, there is just one loop, with the two variables:

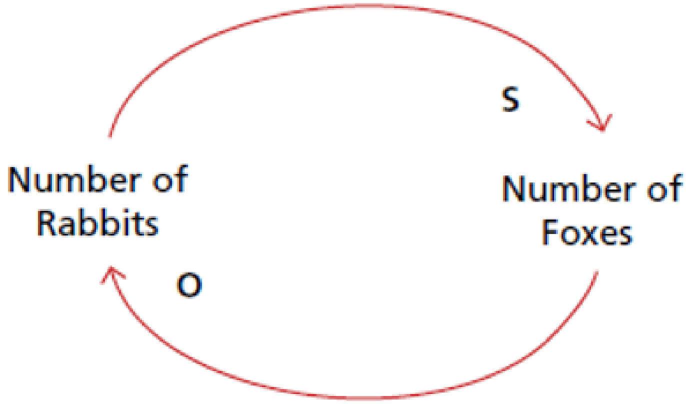


Next, ask how does one variable affect another?

If an increase in one variable causes an increase in another variable, the direction of the change is the same, which is indicated by an "S" by the arrow's head. If an increase in a variable causes a decrease in another variable, the direction of the change is the opposite, which is indicated by an "O" next to the arrow's head.

As the number of rabbits increases, the number of foxes increases—so that is the same and we write an "S" by the arrow pointing to "Number of Foxes."

But as the number of foxes increases, eventually the number of rabbits will decrease, so the change is opposite, and we write an "O" by the arrow pointing to "Number of Rabbits."

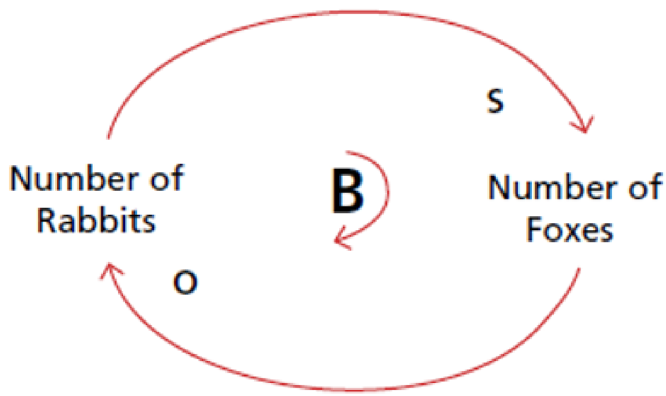


Finally, determine the change dynamic that the loop is describing. These are either balancing dynamics or reinforcing dynamics.

In a balancing loop the same variables oscillate over time, changing direction every time you read through the loop. This indicates that the system is seeking to maintain an equilibrium of some kind within the larger system. When a loop has a balancing dynamic, a "B" is drawn in the middle of the loop.

In a reinforcing loop the same variables continue in only one direction over time. Reinforcing loops can go in either direction; they can grow bigger and bigger until limits of growth are reached, or they can decrease to the point of extinction, death, bankruptcy, etc. When a loop has a reinforcing dynamic, an 'R' is drawn in the middle of the loop.

With our foxes and rabbits, the population of each oscillates over time. (Note that we see this oscillation in the behavior over time graphs that are drawn above in Step 4, Sketch the Trends.) This is a balancing loop, so we place a "B" in the middle of our loop.



Note that this is another way to show what we saw in the connection circle.

A stock/flow diagram is a drawing which shows a stock and its inflows and outflows. In addition to helping us see the relationship between the variables, stock/flow diagrams help us to identify stocks and the factors that increase and decrease those stocks.

To use a stock/flow diagram to better understand an issue: First, identify the important stocks in the story. (These are typically the variables that have been named in previous steps of the analysis.)

In our rabbit and fox story, we have two stocks: Number of rabbits and number of foxes.

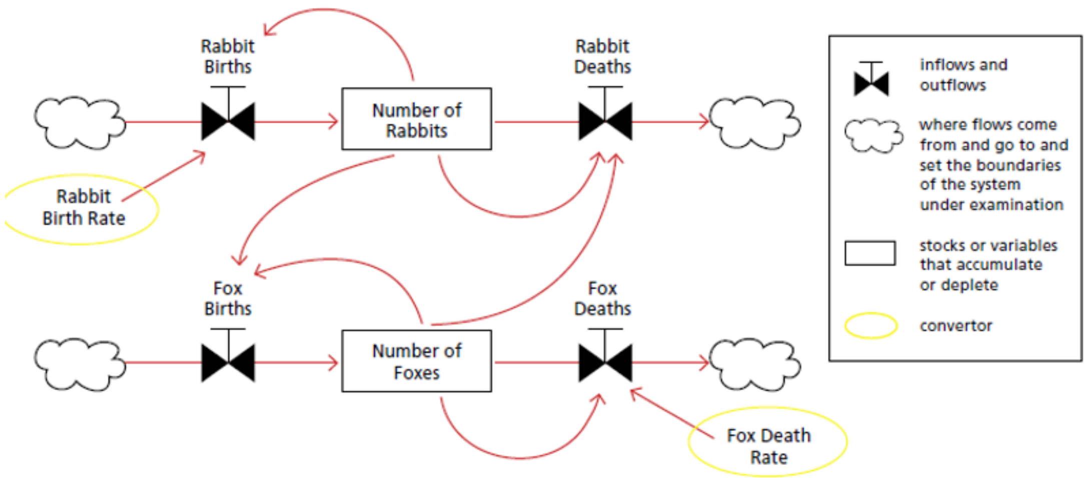
Next, determine the flows—the actions or processes responsible for increasing or decreasing the size of the stock.

For our story we will assume that only births and deaths of the animals will impact their numbers. (Note that if we wanted to expand our analysis we could consider other factors that impact the size of a population in the area, such as migration in/out of the area, which is impacted by carrying capacity. For our example, we'll just look at births and deaths.)

The next step is to ask if there's anything that affects the flows we identified. Any information that affects the flow is called a converter. Where applicable, write the converter in our diagram and draw an arrow from it to the affected flow.

In our story, rabbit births are affected by the rabbit birth rate. The fox deaths are affected by the fox death rate. Rabbit birth rate and fox death rate are converters.

Finally, draw arrows in the diagram to indicate where you think there are causal relationships.



Step 6: Look for leverage for sustainability

At this point, some readers may be asking, "So what? How does all this analysis of variables and causal loops help everyday citizens deal with sustainability issues?" Good question!

To understand the answer, we need to weave into our systems analysis a critical missing component: Humans' impact on the natural world. For a variety of reasons—often good ones—humans disrupt the patterns in nature. In systems thinking language, we could say that our daily actions impact one or more variables in a system. Because many people are unaware that when they tinker with one part of a system, it affects everything connected to it, we end up with unintended consequences, such as overpopulation and climate change. Systems thinking helps us see how our actions may or may not contribute to the sustainability of our environments.

Once we know how the natural patterns of a living system work separate from human impact, we can more easily see where and how people's choices have interrupted and redirected cycles. We can then consider ways to shift to more sustainable options based on new choices.

Let us return to our predator/prey scenario with the foxes and rabbits. Now that we have a deeper understanding of how the population changes, let us see how human activity can shift those dynamics, and what we can do about it.

In the following section, we revisit steps one through five and then move into the sixth step—looking for leverage for sustainability.

The sixth step

The sixth step of looking for leverage requires reviewing steps one through five again—this time with the human behavior element added into the story. Even though it seems iterative, it's important not to skip this step! Some powerful learnings can happen when we see how human actions change the dynamics in nature. We often find the famous line from the Pogo cartoon to be true: "We have met the enemy and they is us." Seeing cause and effect in a new light helps us shift away from a stance of blaming others, or utter helplessness. We begin to see environmental problems from a stance of personal responsibility.

Take Two: Considering the Human Impact

Step 1: Tell the story

Let's say that a farmer with chickens has moved out near our prairie inhabited by foxes and rabbits. The farmer's cooped-up chickens have been an easy form of additional prey for the foxes. The farmer has been protecting his hens by shooting any foxes that he sees near the farm. He has started to notice that an excessive number of rabbits are beginning to come onto his farm.

Step 2: Name the variables

We are still examining populations of foxes and rabbits. There is a new variable about the chicken farmer and his actions: Let's call it 'number of foxes killed by farmer'.

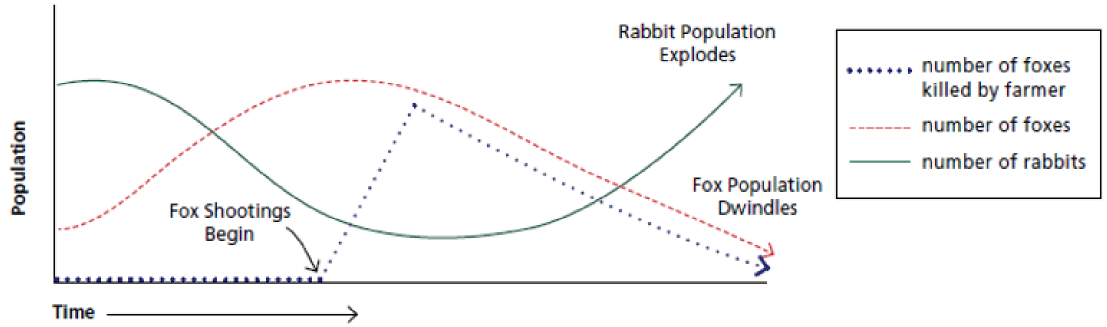
- Number of foxes
- Number of rabbits
- Number of foxes killed by farmer

Step 3: Determine the system boundaries

Our analysis has expanded to include a human activity—that of the farmer killing the foxes because of its direct impact on the fox population.

Step 4: Sketch the trends

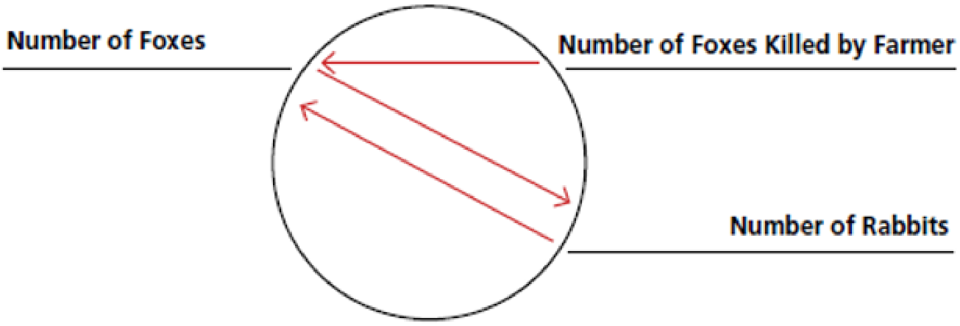
What does a behavior over time graph look like now?



Like the first graph, this behavior over time graph is a representation of our story; unlike the first graph, it has none of the oscillations of the original scenario. As the population of foxes decreases, the rabbit population seems to explode.

Step 5: Make the system visible

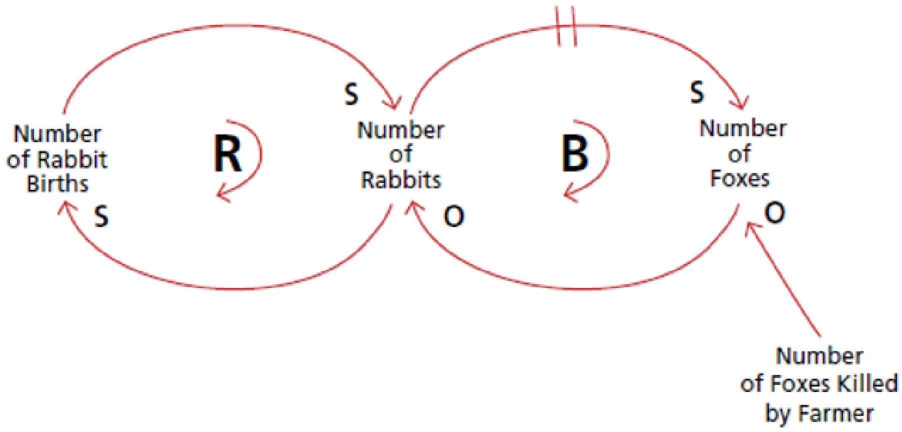
Make a new connection circle which includes the new variable about the farmer.



In our revised story, the number of foxes is impacted both by the number of rabbits they have available for food and by the number of foxes killed by the farmer.

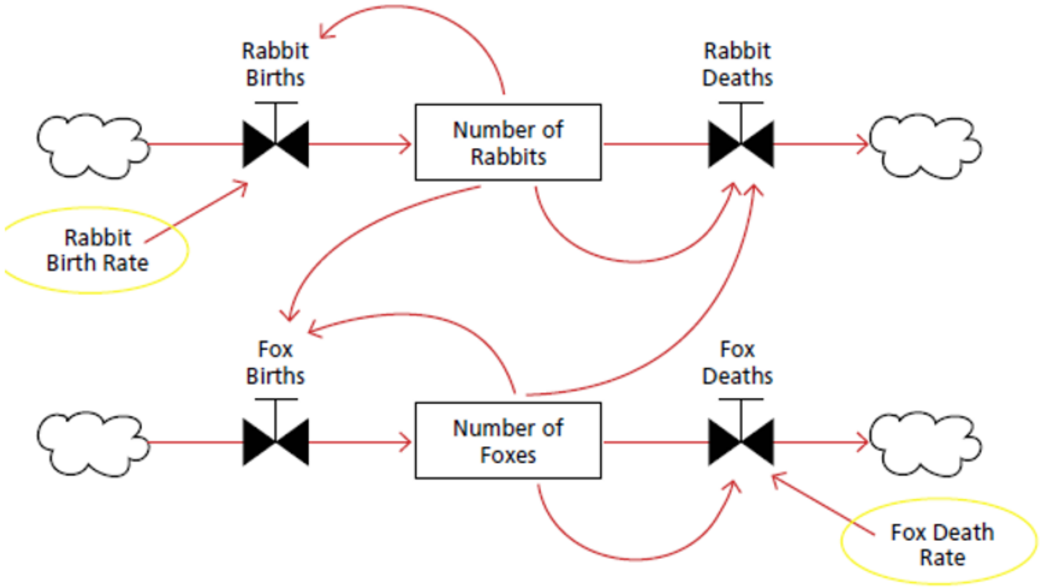
So, why does the rabbit population explode?

To explain the rabbit population explosion resulting from the decline in fox population, our new story is more accurately represented with the diagram below which includes two feedback loops—the simple predator-prey balancing feedback loop which we drew earlier and a reinforcing feedback loop which describes the rabbit population growth that the farmer is experiencing (more rabbits results in more rabbit births and more rabbit births results in even more rabbits and so on).



In our new story, the rabbit birth loop now dominates the dynamics of this system and better represents the trend that the farmer is seeing—more rabbits. In other words, the reinforcing loop is no longer kept in check by the balancing loop, and the result is an explosion in the rabbit population.

A new stock/flow diagram would remain essentially the same, as its structure already includes the birth and death rates of rabbits and foxes.



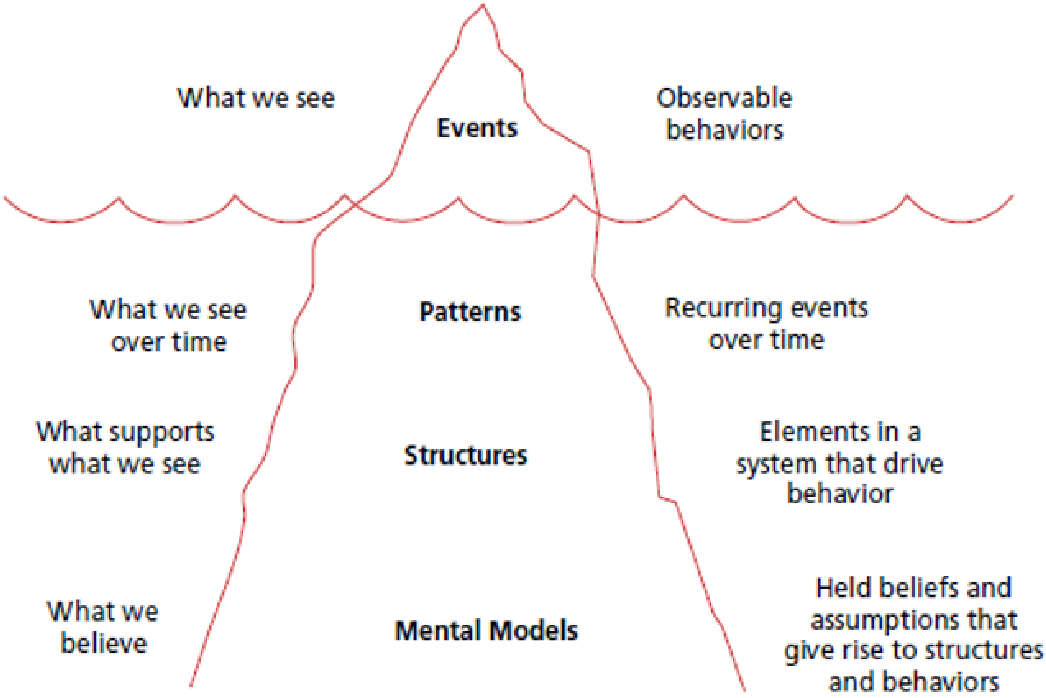
Now, reflect on all of the new information, and its implications. Consider what questions it suggests about future trends.

In the short term, shooting foxes may seem like a necessary part of living on the prairie to protect one's livestock. But what would happen over time? Without the foxes to prey on rabbits, the rabbit population will grow. What consequences might result? Over time, there may be a rabbit population explosion, creating its own set of problems —including endangering the farmer's crops (which the rabbits would eat). Thus, a more sustainable solution is needed so that the farmer, chickens, rabbits, and foxes can all co-exist.

<u>Step 6: Look for leverage for sustainability</u>

The final step in our analysis may be the most rewarding because it leads us to think about new ways of doing things in a high-leverage way. By high leverage, we mean a single change that causes a disproportionately large effect on the system. One useful model for identifying leverage is the Iceberg Model. In systems thinking, the iceberg is a metaphor to explore the unseen but still present structural and cultural influences 'below the waterline' that are driving human choices within a system.

The Iceberg Model analyzes human behaviors within a complex system through considering them at increasingly 'deeper' levels: first, as a single event; then, as a pattern of events; then, looking at the larger structures that help drive behavior, and at the deepest level, the mental models (assumptions or worldviews) that people may be holding about their behaviors. Let's descend the Iceberg Model and look at each of these levels.



Event: To use the iceberg, consider the story under analysis as you would an iceberg where at first just the 'tip of the iceberg' is seen. This is typically a single event that in itself seems relatively harmless. In issues of environmental sustainability, this is usually a single human action—throwing away a recyclable bottle, dumping oil down the drain, or driving a short distance instead of biking or walking.

Let's have our 'tip of the iceberg' event be the shooting of a single fox.

Pattern: Next, consider if the 'tip of the iceberg' might represent a trend. Does it happen more than once? If so, what does the pattern of events look like? (This can be described in words or in a behavior over time graph like is presented in Step 4.)

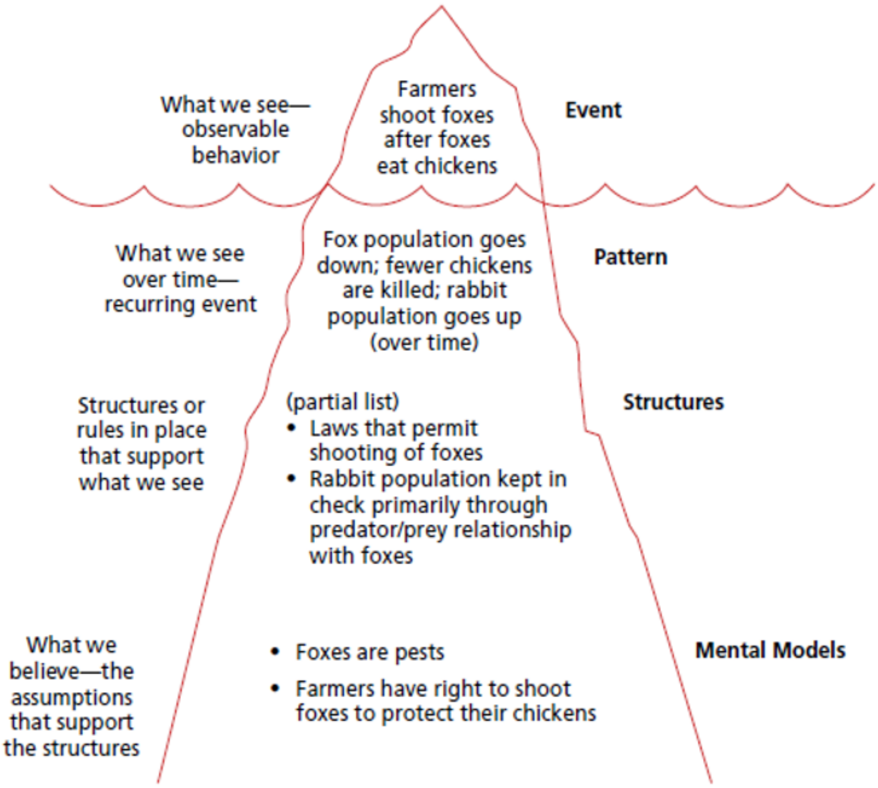
With the shooting of foxes over time, their number decreases over time, which results in the rabbit population increasing over time.

Structure: By structure we mean elements in an environment that help give boundaries and shape to the behaviors we see. There are many kinds of structures—some natural and some human-made.

Examples of structures found in nature include:
• Food chain and predator/prey relationships
• Literal structural shapes of organisms (plant, tree, animal, etc.)

Examples of structures made by people include:
• Rules or laws that govern behavior
• Literal structures like a building or fence

There are many structures in place in the prairie/farm example. Here are just two of them.
• Laws that permit shooting of foxes
• Rabbit population kept in check primarily through predator/prey relationship with foxes



Mental Models are the deep beliefs that we hold about how the world works. It can sometimes be challenging to identify our own mental models because they are often embedded into how we think. A powerful aspect of doing systems thinking work in groups is surfacing where mental models exist and how they have led to the creation of certain structures.

While we cannot know without asking the farmer directly, let us assume that one mental model the farmer holds is that shooting foxes is the easiest way to protect chickens. Another may be that foxes are enemies and need to be eradicated.

See how it helps us think about high leverage change—that is, a place where a small change makes a significant impact. While citizens can look at a system through an iceberg model and attempt to make changes at any level of the iceberg, the most sustainable change often occurs with shifts in mental models.

If the goal is peaceful co-existence between the farmer, his chickens, and the foxes, a shift to a mental model such as foxes play an important role in the ecosystem is needed. Once that belief is adopted, creative solutions to keep the foxes alive but away from the chickens—such as reinforcing his chicken coop—can be considered. Such solutions would allow the prairie system, with its populations of foxes and rabbits, to return to its natural and sustainable dynamics.

HOW TO SELECT LEARNING ACTIVITIES THAT CAN BE ENHANCED BY SYSTEMS THINKING

Some learning activities are better suited than others for enhancement with systems thinking. In sorting through the activities in Project WET, Project WILD Aquatic, and Project Learning Tree for this guidebook, specific criteria were used to determine which ones were best suited for integrating systems thinking. These criteria, along with key words to help select an activity, are described below.

- Interconnectedness. The first quality to look for is an activity that involves a system, that is, two or more parts in a web of relationships, like a food chain or ecosystem. Variables can be identified and connections between them can be easily made through visual tools like connection circles or causal loop diagrams.

Words to look for in the Activity Objectives: System, interconnection, web, interrelated, interdependent, relationships

- Human-environment interaction. The activity focuses on human choices and their impact on the environment over time. In particular, students are encouraged to think about how and why citizens, organizations, and governments impact the systems under analysis. The S.T.O.P. for Systems Understanding (or just the Iceberg Model) can help students connect the ways in which their single decisions can influence a larger system.

Words to look for in the Activity Objectives: People, choices, human impact, resource management, population control

- Patterns of change over time. The activity references a discernable pattern of behavior (i.e., steady decline, increase, or oscillations). Behavior over time graphs can be drawn from analyzing the story.

Words to look for in the Activity Objectives: Growth, decline, fluctuations, oscillations, trend

- Feedback in the system. The activity describes relationships where a change in one variable affects another variable, which feeds back to change the first variable, repeating in a circular nature. This feedback can be drawn with causal loop diagrams.

Words to look for in the Activity Objectives: Cause and effect, feedback, reinforcing, balancing, perpetuating, stabilizing

- Change in stock level. The story in the activity describes the level of a stock increasing or decreasing over time (e.g., number of trees in a forest or population of animals). A stock/flow diagram can be used to show the flows and feedback which impact the level of a stock.

Words to look for in the Activity Objectives: Accumulation, depletion, stock, flow, number of, level of, rate of change, population, growth

In the following table, learning activities from two Project Learning Tree modules are evaluated using the systems thinking criteria described above.

Learning Activities from

Project Learning Tree:

Secondary Environmental
Education Program

	Interconnections	Human-environment interaction	Patterns of change over time	Feedback in the system	Change in stock level
Exploring Environmental Issues: Places We Live (2006)					
Personal Places		■			
Community Character	■	■	■		■
Mapping Your Community Through Time	■	■	■		
Neighborhood Design	■	■	■		
Green Space	■	■	■	■	■
A Vision for the Future		■	■		
Far-Reaching Decisions	■	■	■	■	■
Regional Community Issues: The Ogallala Aquifer	■	■	■	■	■
The Changing Forest: Forest Ecology (2006)					
Adopt-a-Forest	■				
Cast of Thousands	■				
The Nature of Plants	■		■		
Home Sweet Home	■	■	■	■	■
Saga of the Gypsy Moth	■	■	■	■	■
Story of Succession	■	■	■	■	■
Understanding Fire	■	■	■	■	■
Fire Management	■	■	■	■	■

LEARNING ACTIVITY 1: WHEN A WHALE IS RIGHT

Original text from Project WILD Aquatic with integration of systems thinking concepts and tools.

Note: The original When a Whale is Right text from Project WILD Aquatic appears in black and can be found in Appendix B. The new text that has been added for the systems thinking integration appears in brown.

When a Whale is Right with Integration of Systems Thinking Concepts and Tools

Learning Objectives

Objectives
Students should be able to: 1. Describe general characteristics and status of whales. 2. Name the key elements (variables) in the story of the whales. 3. Draw behavior over time graphs to show how the key variables in the whale story change over time. 4. Identify and graphically represent the relationships among the key variables in the whale story using systems thinking tools (make system visible). 5. Explain how international alliances affect wildlife. 6. Evaluate the possible impact of wildlife issues on alliances and other relationships between and among nations.

Method

Students hold hypothetical meeting of the International Whaling Commission.

Materials

Writing materials, research materials

Background

Whales are the largest animals on Earth. There are approximately 80 known species of whales, which range in size from approximately 4 to almost 100 feet in length, and from 160 pounds to 220 tons in weight. Whales are mammals, bearing live young. Some research suggests that whales and other Cetacea, including the dolphins, are creatures of such intelligence that, among other things, they have unusual capacities for communication.

Out of concern for maintaining viable populations of whales, the International Whaling Commission (IWC) was established under the International Convention for the Regulation of Whaling. This treaty was signed in December 1946. The main duty of the IWC is to keep under review and revise as necessary the measures laid down in the Schedule to the Convention, which governs the conduct of whaling throughout the world. Those measures provide for the complete protection of certain whale species, designate specified areas as whale sanctuaries, set limits on the numbers and size of whales that may be taken, prescribe open and closed seasons and areas for whaling, and prohibit the capture of suckling calves and female whales accompanied by calves. The compilation of catch reports and other statistical and biological records is also required.

In addition, the Commission encourages, coordinates, and funds whale research, publishes the results of scientific research, and promotes studies into related matters. Membership in the IWC is open to any country in the world that formally adheres to the 1946 Convention.

There are many stocks or populations of the twelve species of "great whales." Many of those have been depleted by overexploitation, some seriously, both in recent times and in earlier centuries. Fortunately, several species are showing signs of increase since their protection. Like any oyher animal population, whales have a natural capacity to increase and a natural rate of mortality. A stock remains more or less in equilibrium at its initial level because those two factors balance one another. If the number of whales in a stock is reduced, the population will begin to rebound—possibly as a result of greater food availability—by higher pregnancy rates, earlier maturation, increased survival rates, or a combination of these factors.

In 1975, a new management policy for whales was adopted by the IWC using those characteristics. This policy was designed to bring all stocks to the levels that provide the greatest long-term harvests, as it sets catch limits for individual stocks below their sustainable yields. However, because of uncertainties in the scientific analysis and, therefore, the precise status of the various whale stocks, the IWC decided at its meeting in 1982 that there should be a pause in commercial whaling on all whale stocks from 1985 to 1986. A Revised Management Procedure has been developed subsequently, which the commission accepted and endorsed in 1994, but it has yet to be implemented. This plan balances the somewhat conflicting requirements to ensure that the risk to individual stocks is not seriously increased, while allowing the highest continuing yield. It is an important step in the development of wildlife resource management because it takes into account the inevitable scientific uncertainty and requires relatively simple data to obtain information (knowledge of population size, past and present catches, and stock identity).

The pause in commercial whaling does not affect aboriginal subsistence whaling, which is permitted from Denmark (Greenland, fin and minke whales), the Russian Federation (Siberia, gray whales), St. Vincent and the Grenadines (humpback whales), and the United States (Alaska, bowhead, and occasionally gray whales).

As part of their response to the decision for a pause in commercial whaling, some member governments have implemented major research programs that may include the sampling of whales caught under special permits that the convention allows them to grant.

The commission also sponsors and promotes international research. A major undertaking has been a series of ship surveys of the Antarctic minke whale stocks. This series has now been expanded into a new Southern Hemisphere research program called SOWER. Other funded research included work on developing and improving new techniques such as photo-identification studies, acoustic and satellite/radio tracking of whales, and genetic analysis of populations.

The Scientific Committee has been concentrating on a "Comprehensive Assessment" of whale stocks, defined as an in-depth evaluation of the status of the stocks in the light of management objectives. This latter emphasis led to the development of the Revised Management Procedure. The committee is also working to assess the effects on cetaceans of environmental change, such as global warming, pollution, and whale watching activities.

The commission has no enforcement powers. Beyond economic sanctions and national laws by members, the commission relies on voluntary adherence to its rules. World public opinion is an important force on the commission and its member nations to make and enforce responsible conservation decisions.

S.T.O.P. for Systems Understanding

Systems Analysis in Six Steps

1. Tell the story
2. Name the variables
3. Determine the system boundaries
4. Sketch the trends
   • Behavior over time graphs
5. Make the system visible
   • Connection circles
   • Causal loop diagrams
   • Stock/flow diagrams
6. Look for leverage for sustainability
   • Iceberg Model

Procedure

1. As a class, conduct a systems analysis of the whale story. (See page 32 for possible responses.)

2. Divide the students into four groups. One group will research the International Whaling Commission, one will research nonwhaling nation members of the IWC, one will research whaling nation members of the IWC, and one will research whales.

3. Ask each group to conduct library and Internet research. Possible questions for each group might include the following:

International Whaling Commission

What is the International Whaling Commission? When, why, and how was it established? Who are its members? What members are whaling nations? Are there any active whaling nations that are not members of the IWC? If so, what are their current practices affecting whales? What are the major reasons for and against continued whaling? Include economic, political, cultural, scientific, and ethical considerations.

What positions do member nations tend to take on issues? For what reasons? What are the accomplishments of the IWC? What problems does the IWC face? What is the role of world opinion in affecting the activities of the IWC and its member and nonmember nations? What recent recommendations and regulations has the IWC passed? How effectively does the IWC seem to be in meeting its objectives? What other international agreements affect whales? Which countries participate in these agreements?

Nonwhaling Nation Members of the IWC

Have these nations ever actively engaged in whaling? If yes, what are historic reasons for whaling among people of their nation? For what reasons are these nations now nonwhaling nations? How did they vote on the moratorium decision of 1982? What, if any, national laws do they have involving whales?

Whaling Nation Members of the IWC

What are the historic and contemporary reasons for whaling among the people of their nation? What practices have they used and do they use in killing whales? What regulations, if any, do they support that affects the killing of whales? How did they vote on the moratorium decision of 1982? What, if any, national laws do they have involving whales?

Whale Researchers

How many different kinds of whales exist today in the world? Have any whales become extinct? If yes, which? What are the characteristics of the different whale species? What is the status of each of these species? What is the reproductive rate and success of these species? What population increase is possible? What food and other habitat needs do they have? What species are most hunted and for what purposes, historically and in the present? Which species are most scarce, and which are most abundant? How intelligent might they be? What does the future hold for whales?

1. After students have completed their research, set up the classroom to resemble a meeting hall. Hold a meeting of the IWC attended by scientific advisors and any guests, including other interest groups. Organize discussion and debate among the students, representing different interests (e.g., commercial interests, subsistence hunters, preservationists, animal welfare interests, conservation organizations).

2. The next task is to come up with a set of recommendations and regulations that the IWC, including its member whaling and nonwhaling nations, can agree on. This task may be done through discussion by the whole class or by a subcommittee approach. If done by subcommittee, ask for volunteers to represent the IWC, with representatives of both whaling and nonwhaling nations. They should develop a set of recommendations and regulations to present in written form to the rest of the class for review. Include other interest groups as well. Note whether this approach is actually how the IWC makes decisions.

3. Discuss any final recommendations. Evaluate the possible impact of wildlife issues on relationships between and among nations.

Technology Connections

- Use the Internet to research whales. (See page 278 in Project WILD Aquatic for a link to information on maximizing web searches.)
- Use a video camera to record group presentations.
- Create a web log ("blog") to share information within the groups.
- Use illustration software to create a graphic of the 10 countries which are members of the IWC.
- Create an electronic graph of current population numbers for various whale species.

Extensions

Identify any other international bodies that influence aquatic species of wildlife - research these groups and what issues are of concern to their organizations.

Evaluation

1. List four basic characteristics of two different species of whales.
2. Identify 10 countries that are members of the International Whaling Commission. Indicate the countries that are whaling countries, and list which species of whales they harvest. Explain how each country uses its harvested whales.
3. What is the purpose of the International Whaling Commission? Describe an action the Commission has taken to achieve its purpose. How are actions of the IWC enforced? What is your assessment of the IWC's importance and effectiveness?
4. Summarize your impressions of the impact of this issue—and other wildlife issues, if possible—on alliances and other relationships between and among nations.
5. Name five key variables in the story of the whales.
6. How did your systems analysis of the whale story help you better understand the complexities of wildlife management?

NOTE: The name of this activity is not intended to imply that human use of the whales is, or is not, a right. Students may want to investigate how the right whale was named and discuss various interpretations of the meaning of "right" in this context.

NOTE to TEACHERS: On the following four pages, we offer one set of responses to the 6-step systems analysis of the whale story. Use S.T.O.P. Response to help guide the class activity in Procedure #1 on page 31.

S.T.O.P Response

Applying Systems Thinking to When a Whale is Right

Systems Analysis in Six Steps

1. Tell the story
2. Name the variables
3. Determine the system boundaries
4. Sketch the trends
    • Behavior over time graphs
5. Make the system visible
    • Connection circles
    • Causal loop diagrams
    • Stock/flow diagrams
6. Look for leverage for sustainability
    • Iceberg Model

1. Tell the story

The "story" in When a Whale is Right is described in the Background section of this learning activity. Additional elements of this story may be discovered from the research that students engage in as part of this learning activity.

2. Name the variables

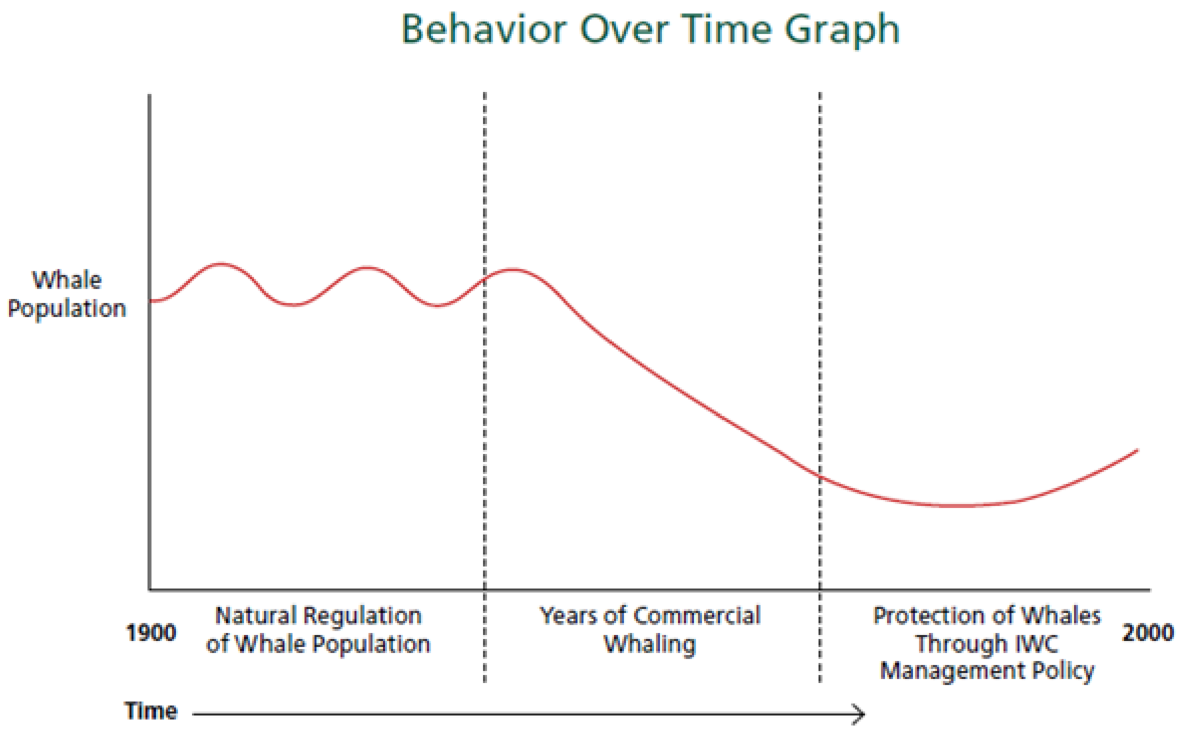
Key Variables

- Whale population
- Birth rate of whales (fertility)
- Death rate of whales (mortality)
- Number of acres set aside as whale sanctuaries
- Length of whale hunting season
- Size of area in which whale hunting is allowed
- Number of whales that can be hunted (catch limit)
- Amount of funding for whale research
- Number of countries who are members of the IWC
- Number of whales killed through hunting (catch)

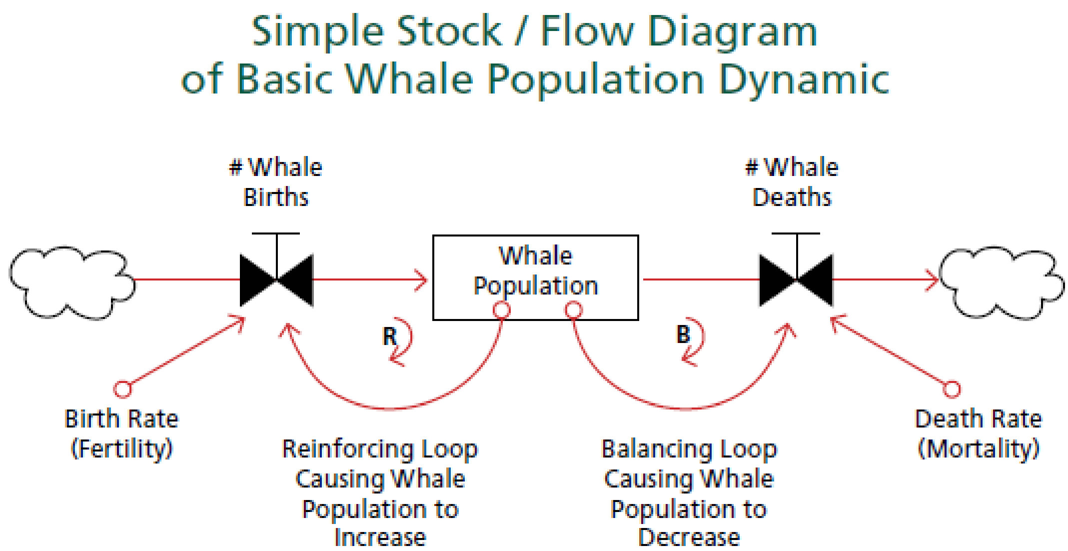
3. Determine the system boundaries

There are number of boundaries in the system under analysis. Students may determine such boundaries as political, geographical, and whale species boundaries.

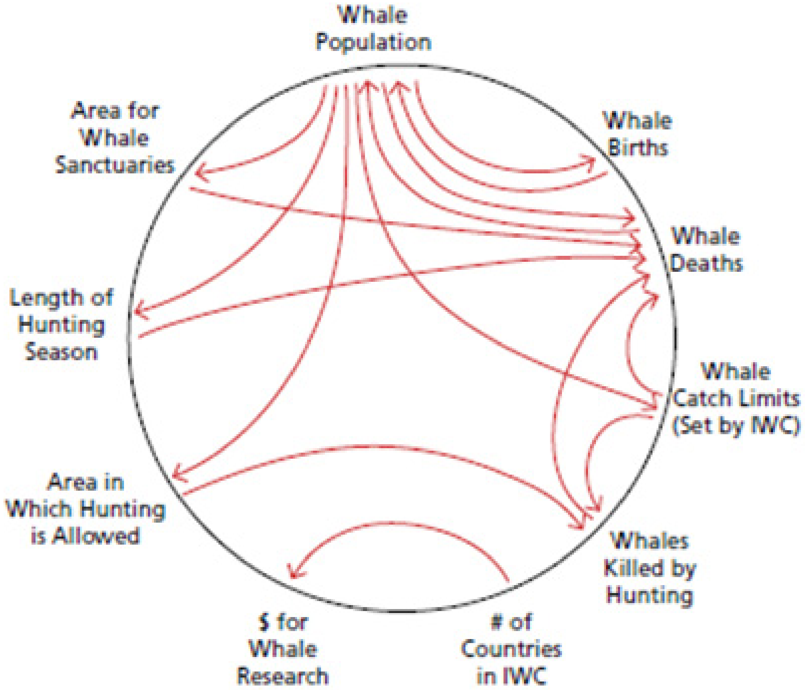
4. Sketch the trends



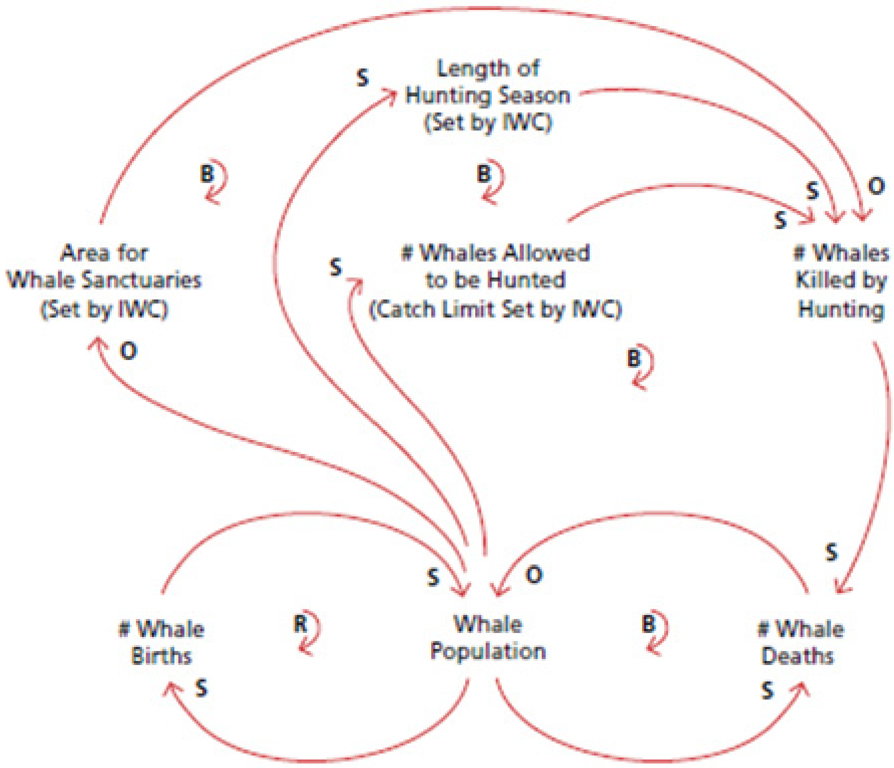
5. Make the system visible



Connection Circle of Key Possible Variables

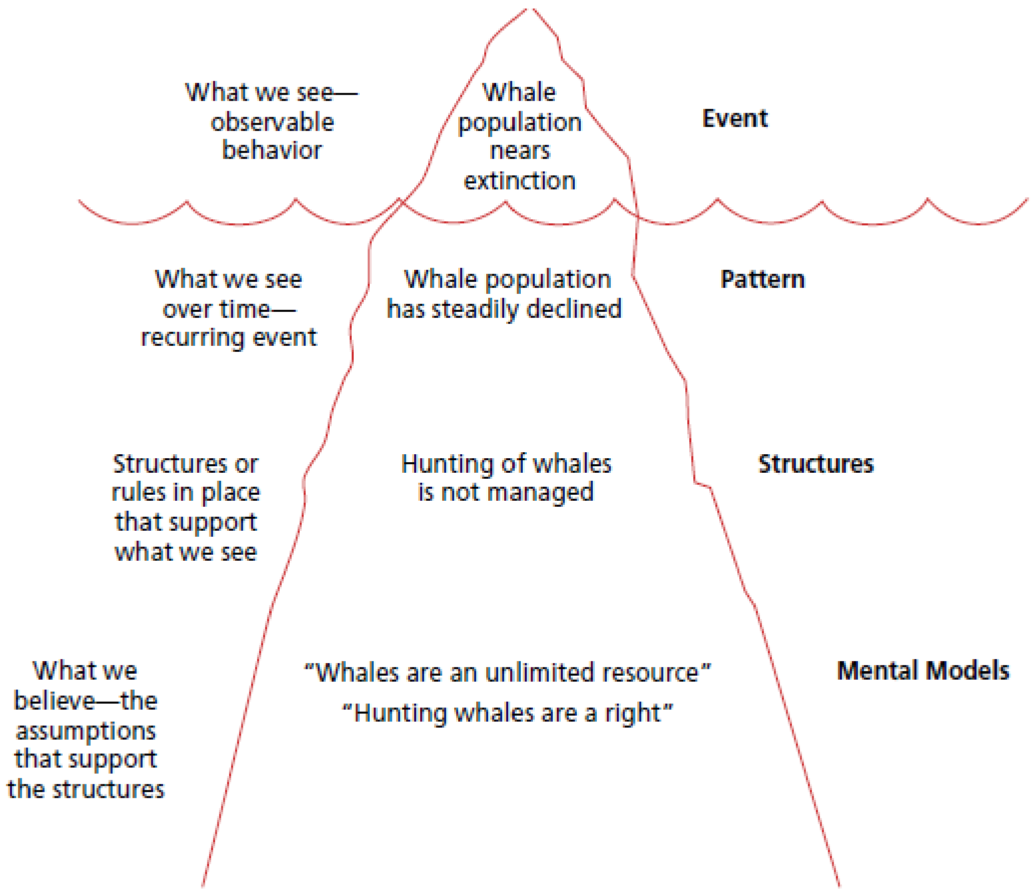


Causal Loop Diagram



6. Look for leverage for sustainability

When we look for leverage for sustainability in the When a Whale is Right story, it is a good idea to use the Iceberg Model, a systems thinking tool which helps us identify the system structures and mental models which cause the behavior (events and patterns) that we see. In When a Whale is Right, what events, patterns, structures, and mental models are present? What possible high leverage actions could we take which would result in more sustainable whale populations?



High Leverage Actions for Sustainability

If the goal is a sustainable whale population, then shifts in mental models such as 'whales are a limited resource' and 'whales are a valuable species and should not be hunted' are needed. Once beliefs such as these are adopted, creative solutions to protect whale populations can be considered and implemented. The creation of the IWC is one such example.

LEARNING ACTIVITY 2: DILEMMA DERBY

Original text from Project WET with integration of systems thinking concepts and tools

Note: The original Dilemma Derby text from Project WET appears in black and can also be found in Appendix C. The new text that has been added for the systems thinking integration appears in brown.

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Dilemma Derby with Integration of Systems Thinking Concepts and Tools

It's a hot August afternoon, and your city is rationing water. You're on your way to an appointment and running late. Suddenly, you see a fire hydrant gushing water onto a street corner. Should you 1) take the time to report it and possibly miss your appointment; 2) proceed to your appointment and assume someone else will report the situation; 3) forget the appointment and play in the water? or 4) ...?

Summary

Students use a 'systems lens' to consider the pros and cons of different solutions to water management issues.

Objectives

Students should be able to:

1. Outline reasons why managing water resources can create dilemmas.
2. Identify, analyze, and elect actions related to a water resource dilemma.
3. Use inquiry and systems thinking to deepen their understanding of dilemmas.

Materials

- Dilemma Cards (These can be glued on index cards and laminated for extra durability.)
- Systems Thinking Reference Card (Give one card to every student.)

Making Connections

People confront dilemmas daily. Students may have weighed the pros and cons of completing a homework assignment versus taking the time to visit with friends. Students may also be familiar with water resource issues such as nonpoint source pollution, water shortages, and wetland restoration. As students investigate problems involving people and water, they will recognize the complexity of managing and protecting water resources.

Through the lens of systems thinking, they will begin to think as 'systems citizens' regarding water quality. Seeing the patterns and connections that link individual choices to large and long-term water resource issues, they will be able to make better-informed choices at the personal level that can impact the quality of water resources at a societal level.

Background

A dilemma is a problematic situation that requires a person to choose from two or more alternatives, each of which can produce desirable or undesirable effects. Managing water resources often creates dilemmas. As with most dilemmas, water resource management can involve conflicts between what one wants to do versus what one believes should be done. For example, disposing of motor oil by dumping it on the ground is easier than the environmentally sound, but more time consuming, alternative of recycling it. Taking a long, hot shower is relaxing, but a short, warm shower—though less comforting—conserves resources. Not voting on a ballot issue that would allocate tax money for water supply projects requires less effort than researching the potential impact of the projects.

People use various approaches to determine a course of action when confronted with a dilemma. These range from flipping a coin to conducting extensive research and attending high-powered meetings. One prudent method consists of listing the alternatives, identifying the pros and cons for each, and projecting possible outcomes. Factors to consider include cost (monetary and environmental), time, energy, persons likely affected, personal values, etc. Emotions and instincts also influence which alternative is chosen. Friends and family can help with the decision-making process as well.

Decision making and problem solving for both systemic and non-systemic problems are critical thinking skills, which are necessary for productive and responsible citizenship. Although confronting dilemmas may not be easy, the experience (whether the outcome is positive or negative) helps people deal with similar conflicts in the future.

Procedure

Warm Up: Thinking Systematically About Dilemmas

Provide students with the following scenario: Your friends have invited you to go out in their boat for an afternoon of water-skiing, swimming, and fishing. You're happy to be included. However, when you get to the dock and ask for your lifejacket, your friends tell you that they forgot to pack the lifejackets when they loaded the equipment early that morning. You are not a very good swimmer and you know it is illegal to go out in a boat without a lifejacket. Still, you don't want to miss out on the fun. What are you going to do?

Tell students that this is a dilemma. Ask them to list reasons why it is a dilemma. Have students describe approaches they have used to resolve similar situations. How have they worked for them? Explain that sometimes in the haste to jump to a quick fix for a problem, we don't always do our best thinking and we end up with unintended (and unwanted) consequences. Systems thinking can help us with the complex problems that are recurring, like many of the water resource management issues. What situations related to water can students recall that could be classified as recurring or ongoing dilemmas? Tell them they will do an exercise that introduces them to a few water-related dilemmas and test their skills at addressing them with the help of systems thinking.

The Activity

Divide students into small groups and give each group one or more Dilemma Cards. Provide the groups with the following instructions:

1. Before breaking into small groups, practice using systems thinking as a class. Reread the opening example (It's a hot August afternoon and your city is rationing water…) and together answer the questions on the Systems Thinking Reference Card.
2. One member of the group (the reader) selects a card and reads the situation aloud. Group members identify reasons why this situation is a dilemma.
3. S.T.O.P. (Systems Thinking Opens Possibilities) to use the Systems Thinking Reference Card. As each dilemma is considered, group members refer to the systems thinking questions on the card and decide which questions help them to think more deeply about the dilemma.
4. The reader presents the list of options to the group. Applying their understanding of the issue through a systems lens, group members discuss the various choices and their consequences; then they decide what they would do and why. They must select one of the available options or identify an alternative course of action. One approach to making a decision is to rate each option. Rank them on a scale of 0-10, with 0 being total disagreement and 10 being total agreement. A rating of 5 indicates "no opinion" or "needs more information."

Wrap Up

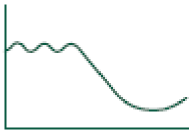
Instruct one member of each group to report their dilemma(s) to the class. He or she should identify why it is a dilemma, what some of the systems issues are, and identify the course of action favored by the group. Students should describe the considerations involved in making their decision. Ask the class to evaluate the selected option and, if applicable, provide alternatives that might be better. Ask them to reflect on their own thinking about the dilemmas. In what ways do the systems questions help them to see issues differently? Do students think they will change the way they will react to real-life water dilemmas? If so, how?

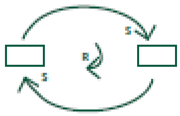
Assessment

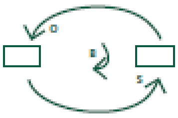
Have students:
- use a ranking system to select a course of action to solve a water-related dilemma (The Activity).
- decide upon a course of action to resolve a water-related dilemma and present reasons for their choice (Wrap Up).
- explain why the management of water resources can create dilemmas (Wrap Up).
- give examples of systems questions that apply to water management dilemmas.

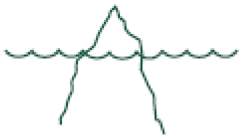
Upon completing the activity for further assessment have students:

- Identify water-related dilemmas in their community and present alternative courses of action, citing pros and cons of each.









Extensions

Have students research the dilemmas presented in the activity and determine if this additional information causes them to change their course of action.

Invite a community planner or a resource manager to speak to the class about a local water-related dilemma and to discuss the problems involved in addressing the dilemma.

Have the students use one of the systems thinking tools (such as behavior over time graph, causal loop diagram, or Iceberg Model) to explain recurring issues or trends.

Resources

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Dilemma Cards

(These can be glued on index cards and laminated for extra durability.)

Dilemma 1:

You've changed the oil in your car. You know the hazards of oil seeping into ground water, yet you are in a hurry to attend a meeting. How will you discard the used oil?

- ☐ Put it in the back of the garage.
- ☐ Place it in a garbage can for disposal in the city/county landfill.
- ☐ Pour it on the ground somewhere out of sight while no one is looking.
- ☐ Burn it.
- ☐ Take it to an approved oil-disposal facility in your area.
- ☐ Other?

Dilemma 2:

You are the mayor of a city which has an area known to flood. A developer wants to build houses on the floodplain. These houses will have a great view of the river, will be conveniently located near the business district, and will entice prosperous people to move to your struggling community. You must make the final decision on the developer's request. Which option will your choose?

- ☐ Inform the developer no building will be allowed.
- ☐ Let the developer build in the flood area
- ☐ Insist the developer elevate the houses on piles of gravel in hopes of avoiding flood damage.
- ☐ Instruct the builder to find an alternative building location out of the floodplain.
- ☐ Other?

Dilemma Cards

(These can be glued on index cards and laminated for extra durability.)

Dilemma 3:

You own a cabin on the lakeshore and there are 400 other cabins facing the lake. Several residents around the lake have been complaining because they think the lake's water quality is poor. (There has been an increase in algae growth and unpleasant odors.) A public service announcement informed the community that these problems likely are caused by septic tanks leaking sewage into the groundwater that feeds into the lake. The announcement advised that septic systems should be checked every three years. It has been almost ten years since yours has been checked, and you know other cabin owners have not checked theirs recently either. Checking your septic tank and fixing the problem could be costly. A fine could be imposed if your septic tank is found to be defective. What are you going to do?

- ☐ Sell the cabin.
- ☐ Do nothing; your tank probably isn't leaking—and if it is, the fine can't be that bad, and you can appeal it.
- ☐ Have your septic tank checked; and if it's leaking, pay to have the sewage pumped and hauled to a safe place.
- ☐ Have your septic tank checked, and if it's leaking, sell the cabin.
- ☐ Have your septic tank checked; fix it if it's leaking, and form a homeowner's association to encourage everyone else to check their tanks, too.
- ☐ Rally the public works system to develop a community water and sewage system and pay to have your cabin hooked up.

Dilemma 4:

You and a friend are hiking, and you see someone dumping a 55-gallon (209-l) drum of a dark liquid into a shallow stream. What should you do?

- ☐ Go over and ask what is going on.
- ☐ Run home and call the police.
- ☐ Wait until the person leaves, then investigate by smelling and feeling the liquid.
- ☐ Take down the license plate number of the nearby truck and report the situation to the fire department.
- ☐ Other?

Dilemma Cards

(These can be glued on index cards and laminated for extra durability.)

Dilemma 5:

You are the governor of your state. Many streams are drying up because water is being diverted for municipal, industrial, and irrigation uses. This has resulted in fish kills. Furthermore, people who like to canoe, raft, and kayak have sent letters of complaint. Industry and agriculture are major sources of income in your state, but you also like its reputation of being a "quiet place" where people can explore scenic rivers. What action will you take?

- ☐ Ask water users to stop using water.
- ☐ Locate and publicize other rivers around the state where people can fish and canoe.
- ☐ Establish a committee to study the problem.
- ☐ Propose constructing a dam and reservoir to store water for release when needed.
- ☐ Buy out the water users so they will have to move to new locations.
- ☐ Establish a water conservation program with incentive.
- ☐ Other?

Dilemma 6:

Your friends have spread a plastic tarp on a hill and are spraying it with a hose. This creates a great water slide. However, sliding repeatedly kills the vegetation on the hillside, and large amounts of water are consumed during the game. Your community has experienced water shortages, but there have been no notices about conserving water for almost a year. You have been invited to take a dive down the hill. What should you do.

- ☐ Report the game to the local authorities and have them cut off the water supply.
- ☐ Change into your bathing suit and join the fun.
- ☐ Try to encourage your friends to do something else, like play basketball or go skateboarding.
- ☐ Join the activity, but only for a short while, encouraging your friends to stop with you.
- ☐ Refuse to join in, and go home to watch television.
- ☐ Lecture your friends on the reasons not to waste water.
- ☐ Other?

Dilemma Cards

(These can be glued on index cards and laminated for extra durability.)

Dilemma 7:

You are the head of a household. You are trying to save money; because your water bills have been large, you have decided to practice water conservation methods to reduce water consumption by family members. Although you have installed low-flow faucets on your showerheads and sinks, your family still insists on taking long, hot showers (sometimes over 20 minutes). What are you going to do?

- ☐ Hold a family meeting to discuss why conservation is important, and ask that shower times be reduced.
- ☐ Order family members to cut down their shower times to five minutes, or else you will turn the hot water heater down or off.
- ☐ Figure the cost of water per gallon and how many gallons flow out of the showerhead each minute. Tell the family you will time their showers, and they will be charged (or their allowances reduced) for each minute over five minutes they shower.
- ☐ Tell family members that you will compare monthly waters bills, and if a bill is lower than the previous one, the money saved will go towards a family trip or entertainment event.
- ☐ Nothing. Your family has the right to bathe for as long as they want.
- ☐ Other?

Dilemma 8:

You are a city council member for a community located adjacent to a large, privately owned wetland. The wetland is home to rare wildlife and migratory birds; some wetland managers indicate that the wetland helps control surface runoff. The owner has decided to sell her land and move to a new location. The land is in an area surrounded by lucrative businesses, where land prices are high and parking is an issue. What should you encourage the council to do?

- ☐ Provide tax incentives to a local development consortium, to help them purchase the land around the wetland and seek permits to develop it for business.
- ☐ Launch an initiative to have the city purchase the land. This will require new taxes and protect the wetland forever.
- ☐ Apply for a permit to fill the wetland with soil from a local hill, developing the wetland into a parking garage and community park.
- ☐ Leave the fate of the wetland to the desires of the community's special interest groups.
- ☐ Wait and see who buys the wetland, and then decide what to do.
- ☐ Other?

Dilemma Cards

(These can be glued on index cards and laminated for extra durability.)

Dilemma 9:

You have moved across country. You love to fish, and you are known for your skill at catching a particular species. This species is not found in the lakes and streams around your new home. A friend from your old neighborhood has offered to bring a tank of these fish to introduce them into one of your local streams. You have heard that introduced organisms (such as starlings, zebra mussels, and purple loosestrife) are competing with native species for resources. However, you have not found the local fishing practices appealing. How should you respond to your friend's offer?

- ☐ Tell your friend to bring the fish; you can't wait to get a population going.
- ☐ Tell your friend you are already learning how to catch a new species of fish, so not to bother.
- ☐ Check with a local fish and wildlife agent to learn if the introduced fish will compete with native fish.
- ☐ Tell your friend to bring the fish; fry up a few and release the rest—they'll probably die anyway.
- ☐ Other?

Dilemma 10:

You are a taxpayer in a coastal state that owns large tracts of land, which historically were wetlands. Through complex engineering, the land has been drained to provide flood protection and to open the area for development and agriculture. These accomplishments have saved lives and improved the standard of living for many residents, while increasing revenue from crop exports. However, populations of some organisms living in the wetlands (such as scarlet ibis, wood storks, and panthers) and along coastal areas (such as coral reefs, lobsters and shrimp) have been greatly reduced. Shrimpers and other fishing industries have suffered from low harvests, and the number of tourists has declined. There is a proposal to restore the historic water flow pattern in some of these areas. This action will increase your taxes. What should you do?

- ☐ Vote down the tax; you pay enough in taxes already.
- ☐ Vote for the tax; a restored, healthy ecosystem is good for everyone.
- ☐ Vote down the tax because communities will be flooded.
- ☐ Vote for the tax because your best friend says you should.
- ☐ Other?

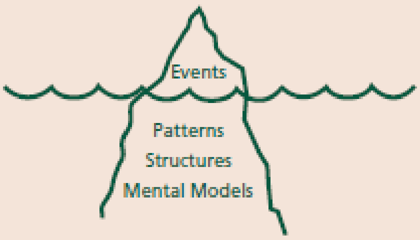
Systems Thinking Reference Card

When faced with a complex issue, a systems thinker asks questions like:

- What happened?
- What length of time is long enough to see patterns in human behavior?
- What structures are in place that may be determining the behaviors we see?
- What underlying beliefs or assumptions are at play in this story?
- Is there any feedback in this system?
- What other perspectives might help us more fully understand this story?

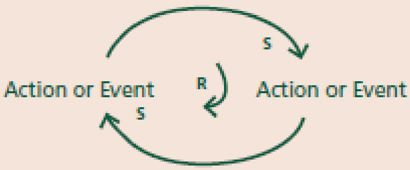
(Front)

Iceberg Model



Behavior Over Time Graph

Causal/Feedback Loop



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Websites to Visit for Additional Systems Thinking Resources

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Linda Booth Sweeney: www.lindaboothsweeney.net
Pegasus Communications: www.pegasuscom.com
Sustainability Institute: www.sustainer.org
The Cloud Institute for Sustainability Education: www.sustainabilityed.org
The Creative Learning Exchange: www.clexchange.org
Waters Foundation – Systems Thinking in Schools: www.watersfoundation.org

APPENDIX B: ORIGINAL TEXT OF WHEN A WHALE IS RIGHT

Source: Council for Environmental Education (CEE). 2011. Project WILD Aquatic: K-12 Curriculum and Activity Guide. Houston, TX: Council for Environmental Education. Pages 94 - 97.

Objectives

Students will (1) describe general characteristics and status of whales, (2) recognize that international alliances affect wildlife, (3) evaluate the possible impact of wildlife issues on alliances and other relationships between and among nations.

Method

Students hold hypothetical meeting of the International Whaling Commission.

Materials

Writing materials, research materials

Background

Whales are the largest animals on Earth. There are approximately 80 known species of whales, which range in size from approximately 4 to almost 100 feet in length, and from 160 pounds to 220 tons in weight. Whales are mammals, bearing live young. Some research suggests that whales and other Cetacea, including the dolphins, are creatures of such intelligence that—among other things—they have unusual capacities for communication.

Out of concern for maintaining viable populations of whales, the International Whaling Commission (IWC) was established under the International Convention for the Regulation of Whaling. This treaty was signed in December 1946. The main duty of the IWC is to keep under review and revise as necessary the measures laid down in the Schedule to the Convention, which governs the conduct of whaling throughout the world. Those measures provide for the complete protection of certain whale species, designate specified areas as whale sanctuaries, set limits on the numbers and size of whales that may be taken, prescribe open and closed seasons and areas for whaling, and prohibit the capture of suckling calves and female whales accompanied by calves. The compilation of catch reports and other statistical and biological records is also required.

In addition, the commission encourages, coordinates, and funds whale research; publishes the results of scientific research; and promotes studies into related matters. Membership in the IWC is open to any country in the world that formally adheres to the 1946 Convention.

There are many stocks or populations of the twelve species of "great whales." Many of those have been depleted by overexploitation, some seriously, both in recent times and in earlier centuries. Fortunately, several species are showing signs of increase since their protection. Whales, like any other animal population, have a natural capacity to increase and a natural rate of mortality. A stock remains more or less in equilibrium at its initial level because those two factors balance one another. If the number of whales in a stock is reduced, the population will begin to rebound—possibly as a result of greater food availability—by higher pregnancy rates, earlier maturation, increased survival rates, or a combination of these factors.

In 1975, a new management policy for whales was adopted by the IWC using those characteristics. This policy was designed to bring all stocks to the levels that provide the greatest long-term harvests, as it sets catch limits for individual stocks below their sustainable yields. However, because of uncertainties in the scientific analysis and, therefore, the precise status of the various whale stocks, the IWC decided at its meeting in 1982 that there should be a pause in commercial whaling on all whale stocks from 1985 to 1986. A Revised Management Procedure has been developed subsequently, which the commission accepted and endorsed in 1994, but is has yet to be implemented. This plan balances the somewhat conflicting requirements to ensure that the risk to individual stocks is not seriously increased, while allowing the highest continuing yield. It is an important step in the development of wildlife resource management in that it takes into account the inevitable scientific uncertainty and requires relatively simple data to obtain information (knowledge of population size, past and present catches, and stock identity).

The pause in commercial whaling does not affect aboriginal subsistence whaling, which is permitted from Denmark (Greenland, fin and minke whales), the Russian Federation (Siberia, gray whales), St. Vincent and the Grenadines (humpback whales), and the United States (Alaska, bowhead, and occasionally gray whales).

As part of their response to the decision for a pause in commercial whaling, some member governments have implemented major research programs that may include the sampling of whales caught under special permits that the convention allows them to grant.

The commission also sponsors and promotes international research. A major undertaking has been a series of ship surveys of the Antarctic minke whale stocks. This series has now been expanded into a new Southern Hemisphere research program called SOWER. Other funded research included work on developing and improving new techniques such as photo-identification studies, acoustic and satellite/radio tracking of whales, and genetic analysis of populations.

The Scientific Committee has been concentrating on a "Comprehensive Assessment" of whale stocks, defined as an in-depth evaluation of the status of the stocks in the light of management objectives. This latter emphasis led to the development of the Revised Management Procedure. The committee is also working to assess the effects on cetaceans of environmental change, such as global warming and pollution, and of whale watching activities.

The commission has no enforcement powers. Beyond economic sanctions and national laws by members, the commission relies on voluntary adherence to its rules. World public opinion is an important force on the commission and its member nations to make and enforce responsible conservation decisions.

<u>Procedure</u>

1. Divide the students into four groups. One group will research the International Whaling Commission, one will research nonwhaling nation members of the IWC, one will research whaling nation members of the IWC, and one will research whales.
2. Ask each group to conduct library and Internet research. Possible questions for each group might include the following:

International Whaling Commission

What is the International Whaling Commission? When, why, and how was it established? Who are its members? What members are whaling nations? Are there any active whaling nations that are not members of the IWC? If so, what are their current practices affecting whales? What are the major reasons for and against continued whaling? Include economic, political, cultural, scientific, and ethical considerations.

What positions do member nations tend to take on issues? For what reasons? What are the accomplishments of the IWC? What problems does the IWC face? What is the role of world opinion in affecting the activities of the IWC and its member and nonmember nations? What recent recommendations and regulations has the IWC passed? How effective does the IWC seem to be in meeting its objectives? What other international agreements affect whales? Which countries participate in these agreements?

Nonwhaling Nation Members of the IWC

Have these nations ever actively engaged in whaling? If yes, what are historic reasons for whaling among people of their nation? For what reasons are these nations now nonwhaling nations? How did they vote on the moratorium decision of 1982? What, if any, national laws do they have involving whales?

Whaling Nation Members of the IWC

What are historic and contemporary reasons for whaling among people of their nation? What practices have they used and do they use in killing whales? What regulations, if any, do they support that affects the killing of whales? How did they vote on the moratorium decision of 1982? What, if any, national laws do they have involving whales?

Whale Researchers

How many different kinds of whales exist today in the world? Have any whales become extinct? If yes, which? What are the characteristics of the different whale species? What is the status of each of these species? What is the reproductive rate and success of these species? What population increase is possible? What food and other habitat needs do they have? What species are most hunted and for what purposes, historically and in the present? Which species are most scarce, and which are most abundant? How intelligent might they be? What does the future hold for whales?

1. After students have completed their research, set up the classroom to resemble a meeting hall. Hold a meeting of the IWC attended by scientific advisors and any guests, including other interest groups. Organize discussion and debate among the students, representing different interests (e.g., commercial interests, subsistence hunters, preservationists, animal welfare interests, conservation organizations).

2. The next task is to come up with a set of recommendations and regulations that the IWC, including its member whaling and nonwhaling nations, can agree on. This task may be done through discussion by the whole class or by a subcommittee approach. If done by subcommittee, ask for volunteers to represent the IWC, with representatives of both whaling and nonwhaling nations. They should come up with a set of recommendations and regulations to present in written form to the rest of the class for review. Include other interest groups as well. Note whether this approach is actually how the IWC makes decisions.

3. Discuss any final recommendations. Evaluate the possible impact of wildlife issues on relationships between and among nations.

Technology Connections

- Use the Internet to research whales. (See page 278 in Project WILD Aquatic for a link to information on maximizing web searches.)
- Use a video camera to record group presentations.
- Create a web log ("blog") to share information within the groups.
- Use illustration software to create a graphic of the 10 countries which are members of the IWC.
- Create an electronic graph of current population numbers for various whale species.

Extensions

Identify any other international bodies that have an influence on aquatic species of wildlife. Research these groups and what issues are of concern to their organizations.

Evaluation

1. List four basic characteristics of two different species of whales.
2. Identify 10 countries that are members of the International Whaling Commission. Indicate the countries that are whaling countries, and list which species of whales they harvest. Explain how each country uses its harvested whales.
3. What is the purpose of the International Whaling Commission? Describe an action the Commission has taken to achieve its purpose. How are actions of the IWC enforced? What is your assessment of the IWC's importance and effectiveness?
4. Summarize your impressions of the impact of this issue—and other wildlife issues, if possible—on alliances and other relationships between and among nations.

NOTE: The name of this activity is not intended to imply that human use of the whales is, or is not, a right. Students may want to investigate how the right whale was named and discuss various interpretations of the meaning of "right" in this context.

APPENDIX C: ORIGINAL TEXT OF DILEMMA DERBY

Source: The Watercourse and Council for Environmental Education. 2000. Project WET: K-12 Curriculum and Activity Guide. Bozeman, MT: The Watercourse and Council for Environmental Education. Pages 377 - 381.

It's a hot August afternoon and your city is rationing water. You're on your way to an appointment and running late. Suddenly, you see a fire hydrant gushing water onto a street corner. Should you 1) take the time to report it and possibly miss your appointment; 2) proceed to your appointment and assume someone else will report the situation; 3) forget the appointment and play in the water? or 4) ...?

Summary

Students debate the pros and cons of different solutions to water management issues.

Objectives

Students will:
- outline reasons why managing water resources can create dilemmas.
- identify, analyze, and elect actions related to a water resource dilemma.

Materials
- Dilemma Cards (These can be glued on index cards and laminated for extra durability.)

Making Connections

People confront dilemmas daily. Students may have weighed the pros and cons of completing a homework assignment versus taking the time to visit with friends. Students may also be familiar with water resource issues such as nonpoint source pollution, water shortages, and wetland restoration. As students investigate problems involving people and water, they will recognize the complexity of managing and protecting water resources.

Background

A dilemma is a problematic situation that requires a person to choose from two or more alternatives, each of which can produce desirable or undesirable effects. Managing water resources often creates dilemmas. As with most dilemmas, water resource management can involve conflicts between what one wants to do versus what one believes should be done. For example, disposing of motor oil by dumping it on the ground is easier than the environmentally sound, but more time consuming, alternative of recycling it. Taking a long, hot shower is relaxing, but a short, warm shower—though less comforting—conserves resources. Not voting on a ballot issue that would allocate tax money for water supply projects requires less effort than researching the potential impact of the projects.

People use various approaches to determine a course of action when confronted with a dilemma. These range from flipping a coin to conducting extensive research and attending high-powered meetings. One prudent method consists of listing the alternatives, identifying the pros and cons for each, and projecting possible outcomes. Factors to consider include cost (monetary and environmental), time, energy, persons likely affected, personal values, etc. Emotions and instincts also influence which alternative is chosen. Friends and family can help with the decision-making process as well.

Decision making and problem solving are critical thinking skills, necessary for productive and responsible citizenship. Although confronting dilemmas may not be easy, the experience (whether the outcome is positive or negative) helps people deal with similar conflicts in the future.

Procedure

Warm Up

Provide students with the following scenario: Your friends have invited you to go out in their boat for an afternoon of water-skiing, swimming, and fishing. You're happy to be included. However, when you get to the dock and ask for your lifejacket, your friends tell you that they forgot to pack the lifejackets when they loaded the equipment early that morning. You are not a very good swimmer and you know it is illegal to go out in a boat without a lifejacket. Still, you don't want to miss out on the fun. What are you going to do?

Tell student that this is a dilemma. Ask them to list reasons why it is a dilemma. Have students describe approaches they have used to resolve similar situations. Inform them that managing water resources can also be a dilemma. What situations related to water can students recall that could be classified as dilemmas? Tell them they are going to do an exercise that introduces them to a few water-related dilemmas and test their skills at addressing them.

The Activity

Divide students into small groups and give each group one or more Dilemma Cards. Provide the groups with the following instructions:

- One member of the group (the reader) selects a card and reads the situation aloud. Group members identify reasons why this situation is a dilemma.
- The reader presents the list of options to the group. Group members discuss the situation and what to do and why. They must select one of the available options or identify an alternative course of action. One approach to making a decision is to rate each option. Rank them on a scale of 0-10, with 0 being total disagreement and 10 being total agreement. A rating of 5 indicates "no opinion" or "needs more information."

Wrap Up

Instruct one member of each group to report their dilemma(s) to the class. He or she should identify why it is a dilemma and identify the course of action favored by the group. Students should describe the considerations involved in making their decision. Ask the class to evaluate the option that was selected, and, if applicable, provide alternatives that might be better. Do students think they will change the way they will react to real-life water dilemmas? If so, how?

Assessment

Have students:

- use a ranking system to select a course of action to solve a water-related dilemma (The Activity).
- decide upon a course of action to resolve a water-related dilemma and present reasons for their choice (Wrap Up).
- explain why the management of water resources can create dilemmas (Wrap Up).

Upon completing the activity for further assessment have students:

- Identify water-related dilemmas in their community and present alternative courses of action, citing pros and cons of each.

<u>Extensions</u>

Have students research the dilemmas presented in the activity and determine if this additional information causes them to change their course of action.

Invite a community planner or a resource manager to speak to the class about a local water-related dilemma and to discuss the problems involved in addressing the dilemma.

<u>Resources</u>

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APPENDIX D: GLOSSARY OF SYSTEMS THINKING CONCEPTS AND TOOLS

Behavior Over Time Graph	A visual tool showing how one or more variables in a system change over time. (See Variable). A systems thinker asks: • How are the key variables in this story changing over time?
Boundary	The line that separates one area from another. A systems thinker creates boundaries to facilitate systems analysis but remembers that boundaries are arbitrary. A systems thinker asks: • Is the boundary we set around this system an appropriate one for our analysis?
Causal Loop Diagram	A drawing that shows the relationships among one or more feedback loops relevant to a story being analyzed. (See Causal Loop/Feedback Loop). The influence of the feedback will always create either a reinforcing or balancing dynamic in the system. (See Causal Loop/Feedback Loop and page 13 for instructions on how to label a causal loop diagram). A systems thinker asks: • What feedback loops are important to include in this causal loop diagram? • How do these loops affect one another? • Where are the delays that affect the dynamics of this system?
Causal Loop/Feedback Loop	A visual tool which shows how two or more variables influence each other. For example, variable A affects B, B affects C, and in turn, C affects A. A systems thinker asks: • How do these variables influence one another? • Is this a balancing or reinforcing feedback loop?
Cause & Effect Relationship	An essential aspect of systems analysis. Whether or not 'A' causes an effect on 'B' is a focus of inquiry to test as either a fact or mental model (see below).
Circular Causality	(See Feedback).
Connection Circle	A visual tool which shows the relationships among variables in a story. A systems thinker asks: • What are the key variables in this story and what are the cause and effect relationships between the variables?

Delay	The amount of time between an action and its consequence. Often people don't wait long enough to see the long-term consequences of their actions. In systems analysis, awareness of delays is critical to understanding the dynamics of the system. A systems thinker asks: • Where are there delays in this feedback loop? • How do these delays affect our behavior?
Event	Something that happens; a single occurrence perceived through the senses. An event that repeats over time is called a pattern. (See Pattern). A systems thinker asks: • What happened? • What did we see, feel, smell, hear, and/or taste?
Feedback	When information about the output of a system is fed back around to the input of the system. Feedback is any reciprocal flow of influence and is the basic building block of systems thinking. In system dynamics, feedback is also known as circular causality and is often depicted graphically as causal loop diagrams. A systems thinker asks: • Where is there feedback in this system?
Flow	A material or information that enters or leaves a stock at some rate over a period of time. (See Stock). A systems thinker asks: • What variables in this story are flows that influence the stocks?
Iceberg Model	A visual tool that illustrates how events or patterns are likely caused by underlying structures in a system and people's mental models. (See Event, Pattern, Structure, and Mental Model). A systems thinker asks: • What system structures and mental models are driving the behavior (events and patterns) that we see?
Leverage Point	A place in a system where making a small change can result in a large improvement in the whole system. A systems thinker asks: • Where in this system could we make small shifts that would make a big difference?
Mental Model	An internal picture about how we view the world. Mental models are often influenced by one's culture. Human behavior and systemic structures are informed by mental models. The view that 'natural resources are unlimited' is an example of a mental model. A systems thinker asks: • What underlying beliefs or assumptions are at play in this story?

Pattern	An event that repeats over time. (See Event). A systems thinker asks: • What keeps happening over time? • What recurring events are we noticing?
Perspective	A particular view or way of looking at a situation. In systems analysis, multiple perspectives help us better understand complex issues. A systems thinker asks: • What other perspectives might help us more fully understand this story?
Stock	A quantity that accumulates over time. A stock increases by a flow in (inflow/input) and decreases by a flow out (outflow/output). For example, the number of trees in a forest is a stock, and trees planted is an inflow and trees harvested is an outflow. Stocks can only be changed by their flows. In systems analysis a stock/flow diagram helps illustrate how a stock changes over time. (See Flow). A systems thinker asks: • What variables in this story are stocks?
Stock/Flow Diagram	A drawing which shows a stock and its inflows and outflows. A stock/flow diagram helps us see what influences the increase or decrease of a stock. For example, whale population is a stock determined by whale births (inflow) and whale deaths (outflow). A bathtub with its faucet and drain is the common metaphor used to explain stocks that increase or decrease, and rates of flow in and out of a stock. (See Stock and Flow). A systems thinker asks: • How is the stock changing over time as determined by the inflows and outflows? • What variables impact inflows and outflows? • What steps can we take to raise or lower the stock to keep it in an acceptable range?
Structure	The way in which the parts of a system are organized and relate to each other. Sometimes the structure of a system can be seen and sometimes it cannot be seen. How desks in a classroom are arranged is an example of a structure we can see. The rules and laws that are in place in our schools and communities are examples of structures that we cannot see. The structure of a system drives its behavior. A systems thinker asks: • What structures are in place in this system that may be determining the behaviors we see?
Time Horizon	A length of time under consideration; the units of a time horizon can vary and be as short as seconds or as long as centuries. A systems thinker chooses the time horizon when analyzing a story. A systems thinker asks: • What time horizon is long enough to see patterns in behavior?

Variable	Any changed or changing factor used to test a hypothesis or prediction in an investigation that could affect the results. In systems analysis, variables are nouns or noun phrases that go up or down over time. For example: Number of trees planted; number of wolves in Yellowstone; parts per million of CO2 in the atmosphere. A systems thinker asks: • What are the key variables in this story? • How does a change in this variable influence other variables in this story?

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Colleen Ponto teaches at Seattle University where she is a core faculty member of the Organization Systems Renewal Graduate Program which specializes in helping adult learners to become designers and leaders of systemic organizational change. She also teaches at the Bainbridge Graduate Institute which offers an MBA in Sustainable Systems where she serves as adjunct faculty. Colleen has been an independent educational and organizational consultant for over 15 years. One of her current passions is helping learners of all ages develop their systems thinking skills; this includes teaching systems thinking to client groups within organizations and to individuals in public workshops. Colleen also leads a nonprofit organization in her community dedicated to environmental education. Before becoming a professor and consultant, Colleen worked as a pulp and paper engineer and production manager for the Weyerhaeuser Paper Company. She received her doctorate in Educational Leadership from Seattle University, her master's degree in Whole Systems Design from Antioch University Seattle, and her bachelor's degree in Paper Science and Engineering from the University of Washington. She lives with her husband and three children near Seattle, Washington.

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