Systems Thinking

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- real in-class testing of materials in at least 3 institutions with external review of student assessment data.
- multiple reviews to ensure the materials meet the InTeGrate materials rubric which codifies best practices in curricular development, student assessment and pedagogic techniques.
- review by external experts for accuracy of the science content.

This page first made public: Oct 24, 2016

Summary

The Systems Thinking Module provides a foundation for systems thinking throughout the InTeGrate materials. Units 1 and 2 of this module are designed to be used early within a course and then reinforced later; Units 3-5 give students data-rich modeling experiences; Unit 6 is an interactive summative activity. Specifically, this module prepares students to address complex systems issues for a sustainable future by 1) identifying the parts of a system and explaining how the parts interact, 2) developing skills to model complex systems using data and examples relevant to the course and 3) applying a systems approach to evaluate a societal challenge. This InTeGrate module fills a key need to educate students about the importance of the systems approach, uses examples that involve data and the construction and manipulation of systems models, and helps students approach complex, interdisciplinary problems.

Strengths of the Module

This module addresses systems thinking in the context of societal issues. Students are engaged through **active learning** (e.g. diagramming, gallery walk, and modeling exercises) and requires interdisciplinary thinking.

Students learn about complex systems and feedbacks, and use systems **modeling** software to explore system responses to changes in the components of the system. They will learn to recognize systems in their everyday lives through a project involving documenting a system they encounter on campus or at home.

Students explore **real Earth system data** to learn about positive and negative feedbacks. The carbon cycle is used to explore quantitative relationships and to develop **writing skills** through describing components of a systems diagram.

Big picture thinking is developed when students make connections between components of the course.

A great fit for courses in:

- Environmental Science
- Introductory Geology
- Oceanography
- Climate Science
- Natural Hazards
- Atmospheric Science
- Interdisciplinary Courses
- Sustainability Courses

Systems thinking is often described as "the whole is greater than the sum of its parts." In order to approach complex problems of the future, students today need to develop the ability to see beyond cause-and-effect relationships to the interconnected nature of real-world systems. This module is designed to help students along an important long-term journey – to be able to understand and describe complex systems that they encounter in their studies and in the world around them. Any of the units in this module could be used alone in a course to improve systems thinking. However, systems thinking typically develops through several weeks or months (or ideally, years) of practice. Spreading the six units of the module across an academic term (i.e., Unit 1 and 2 near the beginning, Units 3, 4, and 5 in the middle, and Unit 6 at the end) allows students to build their skill at systems thinking over time. Content-specific examples are given for each unit, but the module is designed to provide units that can be used in combination with virtually any InTeGrate module or Earth-related science course.

Supported NSF Earth Science Literacy Principles :

- Big Idea 1: Earth scientists use repeatable observations and testable ideas to understand and explain our planet.
- Big Idea 3: Earth is a complex system of interacting rock, water, air, and life.
- Big Idea 6: Life evolves on a dynamic Earth and continuously modifies Earth.
- Big Idea 7: Humans depend on Earth for resources.

Supported NOAA Essential Principles of Climate Science:

> 7. Climate change will have consequences for the Earth system and human lives.

Addressed grand challenges in earth and environmental science :

- Identifying feedback between natural and perturbed systems
- Quantifying consequences, impacts, and effects

Addressed grand challenges in earth system science for global sustainability:

- Develop, enhance, and integrate observation systems to manage global and regional environmental change
- Determine how to anticipate, avoid, and manage disruptive global environmental change.
- Determine institutional, economic, and behavioral changes to enable effective steps toward global sustainability.
- Encourage innovation (and mechanisms for evaluation) in technological, policy, and social responses to achieve global sustainability.

Instructor Stories: How this module was adapted
for use at several institutions »

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Instructor Materials: Overview of the Systems Thinking Module

Module Goal: The goal of this module is to prepare students to address complex systems issues for a sustainable future by:

1. identifying the parts of a system and explaining how the parts interact,
2. developing skills to model complex systems using data and examples relevant to the course, and
3. applying a systems approach to evaluate a societal challenge.

Module Summative Assessment:

> Imagine it is some months from now and you have applied for a job as an ocean science writer for a new popular science magazine called *Our Changing Ocean*. In the interview, the editor asks you:
>
> > "*People say 'everything is connected,' but I rarely get specific examples. Will you convince me of the connectedness and complexity of the ocean?*"
>
> Write what you would say in response by picking any three seemingly unrelated concepts from this course and relating them in the the context of human interaction with the ocean. Be sure to use systems thinking language and specific examples.

Note: As an exam question, completion time is about 20 minutes. In the question above, substitute "ocean" for "Earth" or "climate" or other more relevant term for the course.

Rubric

Topics seemingly unrelated?

- 0=not at all
- 1=somewhat; e.g., two of the topics presented in class the same day
- 2=yes; e.g., sperm whales, forest fires in Minnesota, and Arctic sea ice extent

Accuracy (of descriptions and connections)?

- 0=not at all
- 1=somewhat; e.g., more than one minor incorrect detail
- 2=yes

Convincing connections?

- 0=not at all
- 1=somewhat; e.g., some connections silly or superficial
- 2=yes; using a diagram or words

Connections show complexity?

- 0=not at all
- 1=somewhat; e.g., incomplete understanding of feedback
- 2=yes; using a diagram or words

Relevant to "ocean change"?

- 0=not relevant
- 1=somewhat; e.g., alluded to but not mentioned explicitly
- 2=yes, directly addressed

Specific examples?

- 0=no
- 1=some; e.g., mentions specific places, but insufficient detail for a *Scientific American*-type article
- 2=yes

Writing clear and organized?

- 0=no, very difficult to follow
- 1=somewhat; e.g., lacking summary/overview or other structure, but reader can still follow with some effort
- 2=yes, considering time allotted

Score out of 14 points.

These materials have been reviewed for their alignment with the Next Generation Science Standards. At the top of each page, you can click on the NGSS logo to see the specific connections. Visit InTeGrate and the NGSS to learn more about the process of alignment and how to use InTeGrate materials to implement the NGSS.

NGSS in this Module

The "Systems Thinking" module is structured so that students begin understanding simple systems and then progress to understanding complex thinking. Students learn to work with system modeling software and technical terms for discussing systems and balance and equilibrium in systems. This module engages students in the manipulation of input and output data through the use of the software and analysis of their changes in the system. By the end of the module, students are analyzing and discussing very complex systems within the Earth's system. This module is mainly focused on using computer models and computational thinking to teach systems thinking.

Unit 1Introduction to Systems Thinking — What is a System?

As an introduction to the terminology of systems, this unit should be used early in a course. The unit focuses on a simple conceptual model to introduce the tools of systems thinking, uses a real-world example of a complex societal problem for practice, and offers easily adapted alternatives.

Unit 2Picturing Complexity

Early in a course, students will work collaboratively to create and revise an Earth systems diagram. Building on that experience, students will use photographs to represent a system from their daily lives.

Unit 3Modeling a System

This unit introduces systems modeling, which allows system components to be quantified and manipulated to demonstrate system response. Students use a simple systems model of a bathtub to explore the effect of flow rates on system equilibrium.

Unit 4Feedbacks in a System

Feedbacks are a critical part of many systems. In this unit, students use a systems model to explore the effect of positive (reinforcing) and negative (balancing) feedbacks on system behavior. Model results are then used as a basis for interpreting Arctic sea ice data.

Unit 5Analyzing Complexity

Relatively late in the course, students revise their systems diagrams from Unit 2, based on their expanded knowledge of that system and experience with systems thinking.

Unit 6Systems Thinking Synthesis

This simple in-class exercise is an alternative to standard review sessions and is a way to model the "big-picture thinking" students need to do when thinking about systems. In a round-robin of pairings, students review course content while making connections between components of the course.

Making the Module Work

To adapt all or part of the Systems Thinking module for your classroom, you will also want to read through

- Instructor Stories, which detail how the Systems Thinking module was adapted for use at three different institutions, as well as our guide to
- Adapting InTeGrate Modules and Courses for Your Classroom, which outlines how to effectively use InTeGrate modules and courses.

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how it's working for your peers in their classrooms »

Unit 1: Introduction to Systems Thinking – What is a System?

Lisa Gilbert (Williams College), Deborah Gross (Carleton College), and Karl Kreutz (University of Maine)
Author Profiles
Profile Karl Kreutz, University of Maine
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These materials have been reviewed for their alignment with the Next Generation Science Standards as detailed below. Visit InTeGrate and the NGSS to learn more.

Overview

This focuses on a simple conceptual model to introduce the tools of systems thinking, uses a real-world example of a complex societal problem for practice, and offers easily adapted alternatives.

Science and Engineering Practices

Developing and Using Models: Develop and/or use a model to predict and/or describe phenomena. MS-P2.5:

Developing and Using Models: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system HS-P2.3:

Cross Cutting Concepts

Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. MS-C4.2:

Systems and System Models: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. HS-C4.2:

Systems and System Models: Systems can be designed to do specific tasks. HS-C4.1:

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-C4.3:

Stability and Change: Systems can be designed for greater or lesser stability. HS-C7.4:

Stability and Change: Much of science deals with constructing explanations of how things change and how they remain stable. HS-C7.1:

Stability and Change: Feedback (negative or positive) can stabilize or destabilize a system. HS-C7.3:

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    Resources in this top level collection a) must have scored Exemplary or Very Good in all five review categories, and must also rate as "Exemplary" in at least three of the five categories. The five categories included in the peer review process are

    - Scientific Accuracy
    - Alignment of Learning Goals, Activities, and Assessments
    - Pedagogic Effectiveness
    - Robustness (usability and dependability of all components)
    - Completeness of the ActivitySheet web page

    For more information about the peer review process itself, please see https://serc.carleton.edu/teachearth/activity_review.html.

This page first made public: Oct 24, 2016

Summary

This unit introduces systems and systems thinking. The unit is easily adaptable to any course and includes an introduction of terminology, motivation for using systems thinking, and practice reading, as well as interpreting and evaluating systems diagrams. *Note that an Internet connection and speakers are required to play the audio file in Part 3.*

Learning Goals

Used this activity? Share your experiences and modifications

- Students will be able to define systems terminology (such as open and closed system, reservoir, flux, and feedback loop).
- Students will be able to read and interpret simple systems diagrams.
- Students will be able evaluate a given diagram's appropriateness for a written description of a system.

Context for Use

The unit is intended for use in a course or module for which systems thinking is critical to the goals of the course or module. The examples used are general enough to be used with nearly any course. This unit can stand alone or be used at any point during a course to help promote systems thinking.

Description and Teaching Materials

Materials for this introductory unit are included in the following PowerPoint: Introductory System Slides (PowerPoint 2007 (.pptx) 82kB Oct11 16) (also available as a PDF (Acrobat (PDF) 523kB Oct11 16)). An Internet connection is needed to access the radio piece in Part 3.

Part 1. Knowledge surveys and introduction to systems thinking (5–10 min)

The instructor begins class with a knowledge survey about systems diagrams. Students will complete the same survey at the start and end of class, which will allow them (and you, the instructor) to reflect on their progress.

a) Slides 1–3: Begin class with a knowledge survey

Either on slips of paper, in their notes, with this handout (Microsoft Word 2007 (.docx) 60kB Sep10 16), or using clickers, ask students to answer:

How do you rate your knowledge of systems diagrams right now?

1. I have never heard of systems diagrams.
2. I have heard of systems diagrams, but cannot elaborate.
3. I could explain a little about systems diagrams.
4. If given a systems diagram, I could explain it.
5. I could create a systems diagram and then explain it.

Then, the instructor gives students a short introduction to systems thinking.

b) Slide 4: Prompt students to work individually to describe a bathtub in 2–4 complete sentences.

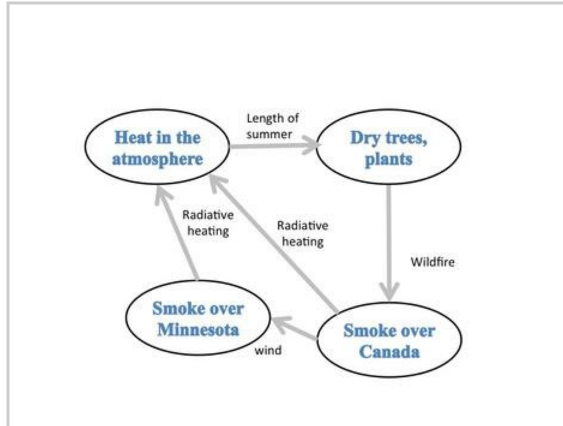
Part 2. Motivation for studying systems thinking and The Bathtub System (10 min)

Slides 5–16: The instructor defines systems terms visually using a bathtub as a system and then shows examples of why systems thinking is important.

Part 3. Example of a system, using systems terminology (20 min)

a) Slide 17: The instructor plays the **first two minutes** of the Minnesota Public Radio piece linked within the PowerPoint. The instructor asks students to list influences on climate. Then, at slide 18, with a partner, students should sort their list of influences into fluxes, reservoirs, and feedbacks.
To access audio file:

- An MP3 file can be downloaded in advance, or
- Audio played on via some browsers at this link: Is climate change fueling more wild fires?.



Incomplete systems diagram in Student Handout. Students modify this diagram based on a news story.

b) Slide 19: The instructor prompts students to work with a partner to answer the following on the Student Handout for Evaluating a System Diagram Activity (Microsoft Word 2007 (.docx) 97kB Jul15 15) (also available as a PDF (Acrobat (PDF) 69kB Jul5 16)):

- Does the diagram fully represent the complexity of the system described by the speaker? If not, add to the diagram.

c) Slide 20–21: The instructor leads a discussion about possible answers to prompt.

Part 4. Expanding the simple bathtub (10–15 min)

Slide 22: The instructor prompts students to draw a diagram of their bathtub at home and use systems vocabulary to explain in a paragraph how it works. How is your bathtub different from the simple open system bathtub we imagined in class? Using systems vocabulary, write a paragraph to explain the differences. The instructor leads a class discussion and wrap-up.

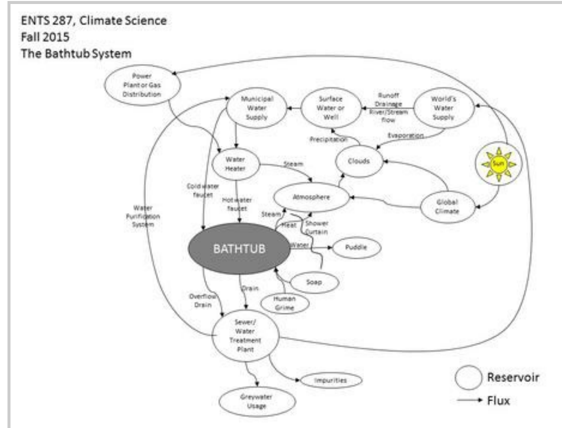
Slide 23: Repeat the knowledge survey.

End of class assessment

Either on slips of paper, in their notes, with this handout (Microsoft Word 2007 (.docx) 60kB Sep10 16), or using clickers, ask students to answer:

How do you rate your knowledge of systems diagrams now?

1. I have never heard of systems diagrams.
2. I have heard of systems diagrams, but cannot elaborate.
3. I could explain a little about systems diagrams.
4. If given a systems diagram, I could explain it.
5. I could create a systems diagram and then explain it.



Draw the bathtub as a system. Example of ideas from 18 different students compiled into one diagram.

***And*, reflect briefly on your learning today:** what aspect of class most helped you improve your knowledge of systems? Why?

Teaching Notes and Tips

Terminology

Many of these terms, including feedback loops, have equivalents in economics, math, and other fields. We have chosen the terms we believe are most common in the natural sciences and concur with Kastens (2010)' Earth and Mind blog post on her choice of reinforcing and balancing feedback loops (in place of positive and negative feedback loops). For instructor reference and to give to students, many systems terms are defined here: Systems Thinking Glossary (Microsoft Word 2007 (.docx) 19kB Dec5 14); also available as a PDF (Acrobat (PDF) 93kB Jun21 16)).

Knowledge Surveys

The start/end of class assessments can be done with any size class in less than a minute. The assessments can be done on paper or with clickers, but it is important for students to reflect on both their final confidence rating and the *difference* between their initial and final ratings. If students only write their ratings in their notes, ask for a show of hands about how many people went up one level or more.

Video alternative to audio

Should an instructor prefer to use a video in place of the MPR audio, a similar-length video provides a reasonable alternative: How Wildfires Affect Climate YouTube video from Michigan Engineering. The instructor would need to slightly alter the student handout (Microsoft Word 2007 (.docx) 97kB Jul15 15) and PowerPoint file for alignment with the video.

Assessment

How do you rate your knowledge of systems diagrams right now, before class?

1. I have never heard of systems diagrams.
2. I have heard of systems diagrams, but cannot elaborate.
3. I could explain a little about systems diagrams.
4. If given a systems diagram, I could explain it.
5. I could create a systems diagram and then explain it.

How do you rate your knowledge of systems diagrams right now, after class?

1. I have never heard of systems diagrams.
2. I have heard of systems diagrams, but cannot elaborate.
3. I could explain a little about systems diagrams.
4. If given a systems diagram, I could explain it.
5. I could create a systems diagram and then explain it.

Reflect briefly on your learning today: what aspect of class most helped you improve your knowledge of systems? Why?

From the MPR piece Student Handout for Evaluating a System Diagram Activity (Microsoft Word 2007 (.docx) 97kB Jul15 15) or PDF version (Acrobat (PDF) 69kB Jul5 16).

1. Write down anything you can identify as a**:**

- flux
- reservoir
- feedback

- Does the diagram fully represent the complexity of the system described by the speaker? If not, add to the diagram.

References and Resources

Systems Thinking Glossary (Microsoft Word 2007 (.docx) 19kB Dec5 14)

Additional background on Earth Systems Thinking: Complex Earth Systems, from Bringing Research on Learning to the Geosciences

Relevant Images/Concepts within other InTeGrate Modules:

- InTeGrate "Climates of Change" Module, Unit 5 systems @play
- InTeGrate "Exploring Geoscience Methods" Module Unit 2, Activity 2.2 (see Step 7)
- Concept maps in InTeGrate: "Humans' Dependence on Earth's Mineral Resources"

Other Systems Diagrams:

This document Examples of Systems Diagrams (Microsoft Word 2007 (.docx) 14kB Sep29 16) (also available as a PDF (Acrobat (PDF) 99kB Sep29 16)) includes a non-comprehensive list of freely-available systems diagrams for a variety of geoscience-relevant systems. The diagrams are presented at a variety of levels and are provided in case the instructor wishes to provide students with a diagram for a class assignment, or for other uses on a case-by-case basis.

Dynamic Visualization:

Many freely-available tools for creating systems diagrams, or causal loop diagrams, include the option to animate, such as LOOPY. An example of how to introduce LOOPY is explained in Visualizing Systems .

Teaching Themes

- Systems Thinking »
- Real-World Connections »
- Geoscience Methods »

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How to Use »

Unit 2: Picturing Complexity

Deborah Gross (Carleton College), Lisa Gilbert (Williams College), and Karl Kreutz (University of Maine)
Author Profiles
Profile deborah gross, Carleton College

Profile Lisa Gilbert, Williams College

Profile Karl Kreutz, University of Maine

These materials have been reviewed for their alignment with the Next Generation Science Standards as detailed below. Visit InTeGrate and the NGSS to learn more.

Overview

The students work collaboratively to create and revise an Earth systems diagram. Building on that experience, students will use photographs to represent a system from their daily lives.

Science and Engineering Practices

Developing and Using Models: Develop and/or use a model to predict and/or describe phenomena. MS-P2.5:

Developing and Using Models: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system HS-P2.3:

Cross Cutting Concepts

Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. MS-C4.2:

Systems and System Models: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. HS-C4.2:

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-C4.3:

Stability and Change: Systems can be designed for greater or lesser stability. HS-C7.4:

Stability and Change: Feedback (negative or positive) can stabilize or destabilize a system. HS-C7.3:

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This page first made public: Oct 24, 2016

Summary

This unit includes an opportunity for students to move from definitions into reading and creating a diagram of a complex system relevant to their course, and then to exploring the connections between the components in the system. An exercise is provided to help students identify complex systems and their component parts from the world around

them. Students will draw and revise a systems diagram, including identifying measurable quantities in the system, and participate in a gallery walk. The unit ends with students constructing a system diagram from photographs they take, and reflecting on their process. *Note that to carry out the activities described in this unit, groups of students will need large sheets of paper and markers, or whiteboard/chalkboard space, to create a diagram.*

Learning Goals

Used this activity? Share your experiences and modifications

- Students will be able to draw and label the diagram for a system relevant to their course.
- Students will be able to identify quantitative information that can be obtained about complex systems as a precursor to generating quantitative models of systems.
- Students will identify and describe a system that they observe in the world around them.
- Students will evaluate how well their system represents the actual system, with attention paid to who generates knowledge about the various components of the system.

Context for Use

The unit is intended for use at the beginning of *any* course or module for which systems thinking, in one way or another, is critical to the goals of the course or module. This lesson should occur early in the course, ideally in a class period shortly after Unit 1, or after key terminology about complex systems (such as source, sink, reservoir, flux) has been introduced. This unit is presented here in a way that could fit into a 50-minute class period, although it would also work broken into individual pieces and spread out across a few consecutive class periods. A homework assignment is provided. Instructors can tailor the activities and assignments to emphasize the aspects which are most relevant to their course.

Description and Teaching Materials

Part 1. Brief Review of Complex System Terminology and Discussion of Steps for Drawing a Diagram of Any Complex System (10–15 min)

In Part 1, the instructor will lead a discussion in which students are asked to review vocabulary and concepts introduced previously about systems diagrams. This is meant to be a brief discussion, to help students retrieve ideas that were discussed previously in their course before asking them to work together to develop and revise the diagram of a course-relevant complex system.

To facilitate this discussion, a presentation is provided (How to Draw a System Diagram PDF (Acrobat (PDF) 846kB Sep11 16) or PowerPoint (PowerPoint 2007 (.pptx) 721kB Sep11 16)) which goes through an example of the process of creating a system diagram, using the example of a heated room (with and without a thermostat). This presentation is meant to help the instructor accomplish three tasks:

1. Review the systems terminology that has been introduced previously (either through the glossary (Systems Thinking Glossary PDF (Acrobat (PDF) 93kB Jun21 16) or Word doc (Microsoft Word 2007 (.docx) 19kB Dec5 14)) and other materials in Unit 1 or other ways).
2. Define a set of steps which can be followed in order to create a system diagram for any system of interest.
3. Mention that different authors will draw different system diagrams for the same system, emphasizing the details that matter to them.

If the instructor uses Unit 2 immediately after Unit 1, this portion of the unit can be compressed or omitted, at the instructor's discretion.

Part 2. Drawing and Revising a Diagram of a Complex System Related to The Course (20–25 min)

After initial discussion, students will gain more experience in creating a complex system diagram themselves. Students will:

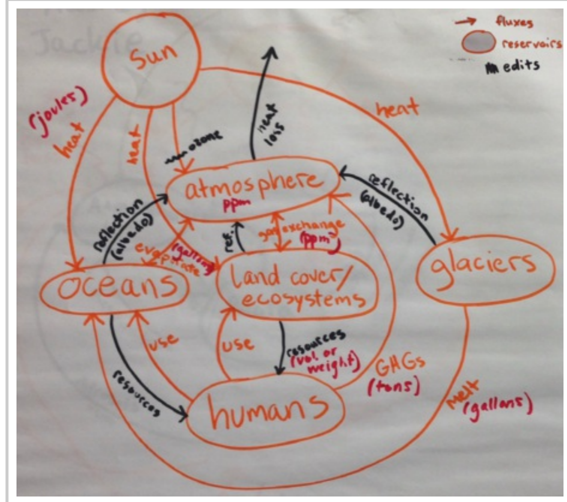
- Work in groups to identify components, behaviors, and linkages within a system designated by their instructor.
- Identify areas in their diagram which could be rendered with more detail, and discuss the level of detail required for different uses/applications of the diagram.
- Create a system diagram with the level of detail needed to explore a topic of interest in their course.

The instructor should decide on a system that is relevant to the course and ask students to use this as the basis for the diagrams that they create, so that all students are working on the same system. Three examples are provided here (How to Label a System Diagram PDF (Acrobat (PDF) 789kB Oct17 16) or PowerPoint (PowerPoint 2007 (.pptx) 823kB Oct17 16)) as examples for the instructor, from a variety of different disciplines: The Carbon Cycle, The Whale Pump, and The Cryosphere. If the instructor wishes to assign one of these systems, the information provided in the presentation goes through the steps students will be asked to carry out, and can provide a model for the level of detail students should achieve. Alternatively, the instructor could assign a different system and use the provided versions as examples for themselves or the students. Many other options of system diagrams are listed in a document in the "References and Resources" section of this page.

Students are given a handout describing this assignment (Draw a System Diagram PDF (Acrobat (PDF) 51kB Sep11 16) or Word doc (Microsoft Word 2007 (.docx) 16kB Sep11 16)), a large Post-it type sheet on the wall and markers (or poster paper and tape, or whiteboard/chalkboard space), and work in groups of 3–5 to generate a diagram of a system. The instructor will provide some guidelines for drawing the system diagram, including the following:

- The fact that students will all diagram the same system, and their diagrams will not be identical.
- The amount of time allotted to this task, so that students can gauge the level of

detail they can include. It is recommended that students spend no more than 10 minutes on this task, as the goal is not to explore every detail of the system but to generate a summary of it.
- The level of artistic detail expected. Students need to be given guidance about whether everything should be represented as boxes or whether components of the diagram should be represented more realistically.



Student diagram of The Earth's Climate System from ENTS 287, Fall 2015, Carleton College.

Students next do a brief (5-minute) "gallery walk" where they look at all or a subset of the diagrams sketched by other groups. In a small class, they may look at all of the other groups' diagrams, while in a large class, they may only see a few. Either way is fine. The "Teaching Notes and Tips" section of this unit includes information about how to structure this active exercise. After looking at the diagrams created by other groups, students will reconvene with their groups at their own diagram and add to it anything that they saw in other groups' diagrams that they think is critical to include, but which they had missed (if resources allow, have the students add this new information using a different color). This should take no more than 5 minutes, and ideally less.

Students should take a picture of their revised diagram before moving on to Part 3. If feasible, the instructor should ask the students to upload their photographs to an online space (course management system, etc.) so that there is a permanent record of it.

Part 3. Labeling a Diagram of a System with Measurable Quantities (10 min)

To begin to transition from qualitative to quantitative representations in systems diagrams, in Part 3 of this unit students are asked to look at a system diagram with an eye toward:

- Identifying those components of the system which can be measured.
- Defining reasonable units for measurable quantities.
- Locating where there are quantitative relationships in their diagram that can be represented with equations.

This assignment is summarized in this student handout (Label a System Diagram PDF (Acrobat (PDF) 78kB Oct17 16) or Word doc (Microsoft Word 2007 (.docx) 15kB Sep11 16)). Students will work in the same diagram-drawing groups to further label their diagrams. The three diagrams of complex systems mentioned above (The Carbon Cycle, The Whale Pump, and The Cryosphere) are annotated to indicate a portion of the items identified in the diagrams which can be measured, possible units, and which can be related with equations (How to Label a System Diagram PDF (Acrobat (PDF) 789kB Oct17 16) or PowerPoint (PowerPoint 2007 (.pptx) 823kB Oct17 16)). The notes section of the PowerPoint version of this file includes information about the terminology and notation used, and suggests issues which can be topics of conversation for any diagram investigated by the class. The set of labels provided in this presentation is not comprehensive—many additional aspects of the system can be measured and can be represented quantitatively. If the instructor uses the provided examples instead of having the students label their own diagrams, the instructor should ask students to find a few more of each on the diagram, to emphasize this point.

Students should take a picture of their annotated diagram before leaving the class, and the instructor should collect and keep the posters. If feasible, the instructor should ask the students to upload their photographs to an online space (course management system, etc.) so that there is a permanent record of it.

Part 4. A Complex System in "The Real World" (Homework)

Part 4 of this unit includes a homework assignment that will allow the instructor to assess the students' facility with representing a complex system through a diagram. If the instructor prefers to use this assignment in the classroom, it can be done as a group or an individual assignment.

As a summative assessment, students are asked to take a series of ~8–10 photographs of a real system that they can observe on their campus/in their locale. This could include a restaurant/dining hall, traffic management at a busy intersection, irrigation of planted or crop areas, etc. They are asked to create an annotated photographic collage (electronic or on paper) in which they use their pictures and text to illustrate how their system works. If the instructor wishes to do this as an in-class activity, a set of images can be provided for students to use rather than having the students acquire their own images. This exercise asks students to practice working with the systems terminology that they have learned and also to explore the way that system diagrams are used to assemble knowledge. The questions they are asked should help them figure out that their diagrams are not perfect representations of the system, that their own knowledge, interests, and potential biases are at play when constructing a diagram, and that any area of a system diagram can be expanded with a greater level of detail, based on the knowledge of the person contributing to it.

Students should be asked to describe in writing and/or labels on their diagram the following aspects of their diagram:

1. The components of the diagram.
2. The connections between components of the diagram. Students should label their diagram with the systems terminology they have learned and identify portions of the diagram with measurable quantities or which could be represented with equations.
3. The areas of their diagram which they feel most secure about (i.e. which do a good job of representing what they are trying to represent).
4. The areas of their diagram which they feel least secure about (i.e. which do a poor job of representing what they are trying to represent or which they do not fully understand). There should be at least five specific questions identified in this section.
5. The type of knowledge they believe would be necessary to gain to be able to improve the areas of the diagram they are least secure about, and some thoughts about who generates this type of knowledge (i.e. geologist, chemist, political scientist, etc.).

In addition, students are specifically asked to reflect, in writing, on what they gain by picturing the system as a system rather than just a list of components or a single relationship.

- An example of a handout for the homework assignment is provided here (Picturing a Complex System Assignment PDF -- private instructor-only file
  Picturing a Complex System Assignment PDF

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- An example of a completed homework assignment is given here (Picturing a Complex System Assignment Example PDF -- private instructor-only file
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- A suggested rubric for assessment of student diagrams and answers is provided here (Picturing a Complex System Assignment Rubric PDF -- private instructor-only file
  Picturing a Complex System Assignment Rubric PDF

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Teaching Notes and Tips

Gallery Walk: A gallery walk provides an opportunity for students to circulate through the room and look at the products of the other groups' efforts; in this unit, Part 2, the products are posters containing system diagrams. More information about Gallery Walk activities is available, although in this version of the activity, no questions are posted around the room—students instead are asked to look at and evaluate the components included by their peers as they evaluate the completeness of their own diagrams, providing them input for revision. If time is a constraint or if there is a large number of groups, each student in a group can be asked to look at three different diagrams from other groups, ensuring that the members of a group have sampled multiple other diagrams.

The homework assignment in Part 4 is optional, but including it provides students with an opportunity to create and work with a diagram for a system that they encounter in their everyday lives.

Assessment

The homework assignment in Part 4 provides an opportunity to assess whether students are appropriately using terminology, identifying measurable quantities in a system diagram, and thinking about the various levels of abstraction that are included in these diagrams. A suggested rubric for assessment of student diagrams and answers is provided (

Rubric as a PDF -- private instructor-only file
Rubric as a PDF

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If students are meeting the "Acceptable" or "Exemplary" criteria in most of the categories, they have sufficient mastery of the ideas of systems diagrams to move ahead to a quantitative approach to complex systems, as presented in Unit 3.

References and Resources

Relevant Images/Concepts within other InTeGrate Modules:

- Earth's Energy Balance
- InTeGrate "Climates of Change" Module, Unit 5 systems @play
- InTeGrate "Exploring Geoscience Methods" Module Unit 2, Activity 2.2 (see Step 7)
- Concept maps in InTeGrate: "Humans' Dependence on Earth's Mineral Resources"

Other Systems Diagrams:

A non-comprehensive list of freely-available systems diagrams for a variety of geoscience-relevant systems is provided here (Examples of Systems Diagrams PDF (Acrobat (PDF) 99kB Sep29 16) or Word doc (Microsoft Word 2007 (.docx) 14kB Sep29 16). The diagrams are presented at a variety of levels and can be used if the instructor wishes to provide students with a different diagram from those examples which are given here.

Teaching Themes

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Unit 3: Modeling a System

Karl Kreutz (University of Maine), Deborah Gross (Carleton College), and Lisa Gilbert (Williams College)
Author Profiles
Profile Karl Kreutz, University of Maine

Profile Lisa Gilbert, Williams College

Profile deborah gross, Carleton College

These materials have been reviewed for their alignment with the Next Generation Science Standards as detailed below. Visit InTeGrate and the NGSS to learn more.

Overview

Students are introduced systems modeling, which allows system components to be quantified and manipulated to demonstrate system response. Students use a simple systems model of a bathtub to explore the effect of flow rates on system equilibrium.

Science and Engineering Practices

Developing and Using Models: Evaluate limitations of a model for a proposed object or tool. MS-P2.1:

Developing and Using Models: Develop or modify a model— based on evidence – to match what happens if a variable or component of a system is changed. MS-P2.2:

Developing and Using Models: Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. MS-P2.4:

Developing and Using Models: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system HS-P2.3:

Developing and Using Models: Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. HS-P2.6:

Cross Cutting Concepts

Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. MS-C4.2:

Systems and System Models: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. HS-C4.2:

Systems and System Models: Systems can be designed to do specific tasks. HS-C4.1:

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-C4.3:

Stability and Change: Systems can be designed for greater or lesser stability. HS-C7.4:

Stability and Change: Much of science deals with constructing explanations of how things change and how they remain stable. HS-C7.1:

Stability and Change: Feedback (negative or positive) can stabilize or destabilize a system. HS-C7.3:

Stability and Change: Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. HS-C7.2:

1. **This material was developed and reviewed through the InTeGrate curricular materials development process.** This rigorous, structured process includes:

    - team-based development to ensure materials are appropriate across multiple educational settings.
    - multiple iterative reviews and feedback cycles through the course of material development with input to the authoring team from both project editors and an external assessment team.
    - real in-class testing of materials in at least 3 institutions with external review of student assessment data.
    - multiple reviews to ensure the materials meet the InTeGrate materials rubric which codifies best practices in curricular development, student assessment and pedagogic techniques.
    - review by external experts for accuracy of the science content.

2. **This activity was selected for the On the Cutting Edge Exemplary Teaching Collection**

    Resources in this top level collection a) must have scored Exemplary or Very Good in all five review categories, and must also rate as “Exemplary” in at least three of the five categories. The five categories included in the peer review process are

    - Scientific Accuracy
    - Alignment of Learning Goals, Activities, and Assessments

- Pedagogic Effectiveness
- Robustness (usability and dependability of all components)
- Completeness of the ActivitySheet web page

For more information about the peer review process itself, please see https://serc.carleton.edu/teachearth/activity_review.html.

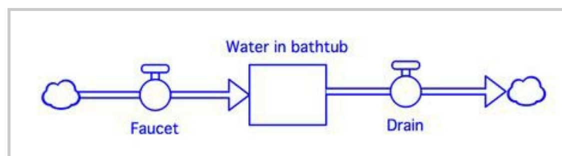
This page first made public: Oct 24, 2016

Summary

This unit introduces systems modeling, which allows students to quantify and manipulate system components to create system responses. Students use a simple systems model of a bathtub to explore the effect of flow rates on system equilibrium. To complete the unit, students will need a method for creating and sharing diagrams (whiteboards, posters, etc.), and will ideally have access to free systems modeling software.

Learning Goals

Used this activity? Share your experiences and modifications



Images from the STELLA bathtub model used in Unit 3 (Systems modeling).

- Students will be able to apply systems vocabulary to the structure of a systems model.
- Students will be able to contrast conditions that produce equilibrium and non-equilibrium behavior in a systems model.
- Students will be able to estimate residence time for a system in equilibrium.

Context for Use

This unit should ideally occur mid-course, after students have been introduced to systems thinking concepts in Units 1 and 2. Unit 3 uses a dynamical system model developed with the STELLA software package. Depending on class setting, instructors have three different approaches for accessing the Bathtub Model (Stella Model (v10 .stmx) 9kB Jan3 17) with students: 1) instructors can use the

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), which contains all the necessary images of model structure, interface, and output. *This approach requires no STELLA software*; 2) instructors can run model experiments on their device, and display to the class for discussion; or 3) students can run model experiments on their devices, either individually or in groups, and the instructor can decide how to facilitate discussion.

This unit may fit into a single 50-minute class period, assuming efficient use of time (i.e., the instructor runs the models [or uses the model images] and displays output for discussion with students, or students come to class with software resources installed and running properly). Student use of models may lead to more in-depth discussion, and will likely also mean the unit requires multiple class periods. Finally, the instructor and students may, if they have the STELLA software package, decide to explore, modify, and/or expand the models in any number of ways; this also would require multiple class periods.

Description and Teaching Materials

If instructors choose to use STELLA software (approach 2 or 3 from above), different options are available depending on classroom setting, platform, and financial considerations.

- Download and install the ***free*** isee Player software available in Windows and Macintosh versions. Models can be run and output interpreted with Player. *Units 3 and 4 can be completed with Player software alone.*
- Purchase, download, and install STELLA software available in Windows and Macintosh versions. Models can be run and output interpreted with STELLA; models can also be modified, output saved, and shared with STELLA.
- Purchase, download, and install the STELLA Modeler for iPad software (also available from the Apple App Store). Models can be run and output interpreted with Modeler for iPad; models can also be modified, output saved, and shared with Modeler for iPad.

Students will need to develop and share diagrams in class; this can be done via whiteboard, large Post-it notes, paper, or electronically. They will also need to complete the Systems modeling worksheet Word doc (Microsoft Word 80kB Sep12 16) (also available as a PDF (Acrobat (PDF) 74kB Sep12 16)), which can be done electronically or as a handout.

The Systems modeling quick start PowerPoint (PowerPoint 2.3MB Jan3 17) (also available as a PDF (Acrobat (PDF) 1.9MB Jan3 17)) has instructions on how to get started using Bathtub Model (Stella Model (v10 .stmx) 9kB Jan3 17). If students will be using Player or STELLA software, they should download the software and review the quick start prior to class.

**Note that the STELLA model and model images used in this unit were created with STELLA Architect v.1 software.*

Part 1. Pre-experiment discussion of systems models (20 min)

Begin class with an instructor-led review of the systems concepts covered in Unit 1 and 2, namely inflow, reservoir, and outflow. Next, introduce systems models using the Systems modeling presentation PowerPoint (PowerPoint 4.2MB Jan3 17) (also available as a PDF (Acrobat (PDF) 4.2MB Jan3 17)). Afterward, if time allows, ask each student/group to identify a single inflow/reservoir/outflow component within the system diagram they developed in Unit 2 (either the group diagrams developed in class, or the homework diagrams developed individually). On a sketch, students/groups should draw the component structure, identify units for the flows and reservoir, and make rough but realistic estimates of flux and reservoir values. Have students/groups share their sketches and ideas with the class. Focus particular attention on distinguishing reservoir examples that may be changing with time from those that are not.

Part 2. Experiment 1 — Equilibrium vs. non-equilibrium (10 min)

- Students should use the Systems modeling worksheet Word doc (Microsoft Word 80kB Sep12 16) (also available as a PDF (Acrobat (PDF) 74kB Sep12 16)) to walk through the experiment. Ideally this would be done in small groups, so that students can work together to answer questions about model output. The instructor can encourage whole class discussion of findings.
  - *Experiment 1a*: Run Bathtub Model (Stella Model (v10 .stmx) 9kB Jan3 17) with the following parameters: Faucet = 1 liter/second; Drain = 1 liter/second; Water in bathtub = 10 liters*;* Discuss results, namely that when inflow and outflow are balanced, the reservoir size does not change with time. Hence, the system is in equilibrium.
  - *Experiment 1b*: Run Bathtub Model (Stella Model (v10 .stmx) 9kB Jan3 17) with the following parameters: Faucet = 2 liters/second; Drain = 1 liter/second; Water in bathtub = 10 liters; Discuss results, where inflow and outflow are not balanced. The reservoir size changes with time (increasing linearly in this case), and the system is therefore in non-equilibrium.
- The instructor should encourage whole class discussion of findings. Model images and discussion notes for instructors are in the ▶ Systems modeling experiment notes PowerPoint -- private instructor-only file
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Part 3. Experiment 2 — Residence time (10 min)

- Students should use the Systems modeling worksheet Word doc (Microsoft Word 80kB Sep12 16) (also available as a PDF (Acrobat (PDF) 74kB Sep12 16)) to walk through the experiment. Ideally this would be done in small groups, so that students can work together to answer questions about model output.
  - *Experiment 2a*: Run Bathtub Model (Stella Model (v10 .stmx) 9kB Jan3 17) with the following parameters: Faucet = 1 liter/second; Drain = 1 liter/second; Water in bathtub = 10 liters; Explain residence time concept, and discuss how to calculate residence time for this model run (residence time here = 10 seconds).
  - *Experiment 2b*: Run Bathtub Model (Stella Model (v10 .stmx) 9kB Jan3 17) with the following parameters: Faucet = 2 liters/second; Drain = 2 liter/second; Water in bathtub = 10 liters; Discuss results, namely that the system is still in equilibrium even though fluxes are doubled (and balanced). Calculate residence time (5 seconds in this case), compare to previous run, and discuss implications of residence time changes for any system including real-world examples.
- The instructor should encourage whole class discussion of findings. Model images and discussion notes for instructors are in the Systems modeling experiment notes PowerPoint -- private instructor-only file
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Part 4. Homework

- As a summative assessment, students are asked to consider a simple inflow/reservoir/outflow system that they likely encounter every day (a parking lot) in the Systems modeling homework Word doc (Microsoft Word 43kB Sep12 16) (also available as a PDF (Acrobat (PDF) 58kB Sep12 16)). Questions emphasize equilibrium, non-equilibrium, and residence time concepts.

Teaching Notes and Tips

While Unit 3 can be done using the model images in the experiment notes alone, we highly recommend using the models interactively in class — the models can be run repeatedly to reinforce concepts, and the instructor (and students) can easily and quickly navigate between different model levels (e.g., interface and model levels).

If students will use models in class, they should have the software installed and models downloaded prior to class. They should also use the Systems modeling quick start PowerPoint (PowerPoint 2.3MB Jan3 17) (also available as a PDF (Acrobat (PDF) 1.9MB Jan3 17)) to become familiar with basic model controls prior to class.

Assessment

- To assess student comprehension during the unit, instructors can collect the Systems modeling worksheet Word doc (Microsoft Word 80kB Sep12 16) (also available as a PDF (Acrobat (PDF) 74kB Sep12 16)) after class.
  - An answer key is provided here as a Word doc -- private instructor-only file
    Word doc

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- The Systems modeling homework Word doc (Microsoft Word 43kB Sep12 16) (also available as a PDF (Acrobat (PDF) 58kB Sep12 16)) assignment provides an opportunity to assess whether students have developed a basic understanding of systems models, how to apply systems vocabulary, and equilibrium and residence time concepts.
    - An answer key for the homework is provided here as a Word doc -- private instructor-only file
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    - A suggested rubric for evaluating student responses is here as a Word doc -- private instructor-only file
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References and Resources

STELLA modeling resources

- Shiflet, A.B., and Shiflet, G.W., 2006, Introduction to Computational Science: Modeling and Simulation for the Sciences, Princeton University Press. *Contains excellent basic tutorials on using STELLA software*
- How to Read a STELLA Model Diagram, from CC Modeling Systems, has a basic instruction to STELLA model diagrams
- iSee Systems' Community page has a number of useful resources related to dynamic system modeling
- iSee Systems' Book Store has a number of books available on dynamic system modeling

System equilibrium and growth/decay

- Information on Equilibrium, Stability, and Behavior Over Time, from *Starting Point*

Residence time

- Example of using hydrologic tracers to characterize residence time: Using Hydrological Tracers to Characterize a Watershed, from *Microbial Life Educational Resources*

Teaching Themes

- Systems Thinking »
- Temporal Reasoning »
- Geoscience Methods »

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Unit 4: Feedbacks in a System

Karl Kreutz (University of Maine), Deborah Gross (Carleton College), and Lisa Gilbert (Williams College)
Author Profiles
Profile Karl Kreutz, University of Maine
Profile Lisa Gilbert, Williams College
Profile deborah gross, Carleton College

These materials have been reviewed for their alignment with the Next Generation Science Standards as detailed below. Visit InTeGrate and the NGSS to learn more.

Overview

Students use a systems model to explore the effect of positive (reinforcing) and negative (balancing) feedbacks on system behavior. Model results are then used as a basis for interpreting Arctic sea ice data.

Science and Engineering Practices

Developing and Using Models: Evaluate limitations of a model for a proposed object or tool. MS-P2.1:

Developing and Using Models: Develop or modify a model— based on evidence – to match what happens if a variable or component of a system is changed. MS-P2.2:

Developing and Using Models: Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. MS-P2.4:

Developing and Using Models: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system HS-P2.3:

Developing and Using Models: Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. HS-P2.6:

Cross Cutting Concepts

Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. MS-C4.2:

Systems and System Models: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. HS-C4.2:

Systems and System Models: Systems can be designed to do specific tasks. HS-C4.1:

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-C4.3:

Stability and Change: Systems can be designed for greater or lesser stability. HS-C7.4:

Stability and Change: Much of science deals with constructing explanations of how things change and how they remain stable. HS-C7.1:

Stability and Change: Feedback (negative or positive) can stabilize or destabilize a system. HS-C7.3:

Stability and Change: Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. HS-C7.2:

Disciplinary Core Ideas

Earth Materials and Systems: Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. HS-ESS2.A1:

1. **This material was developed and reviewed through the InTeGrate curricular materials development process.** This rigorous, structured process includes:

    - team-based development to ensure materials are appropriate across multiple educational settings.
    - multiple iterative reviews and feedback cycles through the course of material development with input to the authoring team from both project editors and an external assessment team.
    - real in-class testing of materials in at least 3 institutions with external review of student assessment data.
    - multiple reviews to ensure the materials meet the InTeGrate materials rubric which codifies best practices in curricular development, student assessment and pedagogic techniques.
    - review by external experts for accuracy of the science content.

2. **This activity was selected for the On the Cutting Edge Exemplary Teaching Collection**

    Resources in this top level collection a) must have scored Exemplary or Very Good in all five review categories, and must also rate as "Exemplary" in at least three of the five categories. The five categories included in the peer review process are

- Scientific Accuracy
- Alignment of Learning Goals, Activities, and Assessments
- Pedagogic Effectiveness
- Robustness (usability and dependability of all components)
- Completeness of the ActivitySheet web page

For more information about the peer review process itself, please see https://serc.carleton.edu/teachearth/activity_review.html.

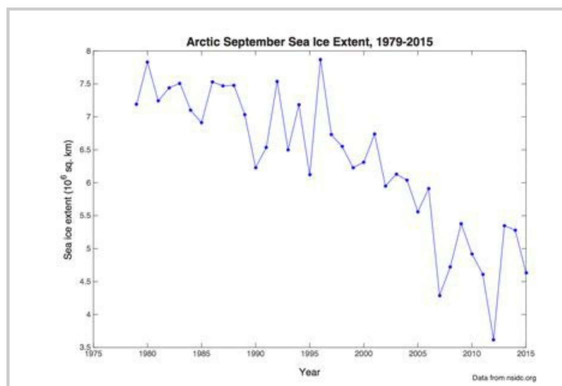
This page first made public: Oct 24, 2016

Summary

Feedbacks are a critical part of many systems. In this unit, students use a systems model to explore the effect of positive (reinforcing) and negative (balancing) feedbacks on system behavior. Model results are then used as a basis for interpreting Arctic sea ice data. To complete the unit, students will ideally have access to free systems modeling software.

Learning Goals

Used this activity? Share your experiences and modifications



Arctic September sea ice extent, 1979-2015. Data from the National Snow and Ice Data Center (nsidc.org).

- Students will be able to identify feedback structure in systems diagrams and models.
- Students will be able to identify the characteristics of positive (reinforcing) and negative (balancing) feedbacks in systems model output.
- Students will evaluate Earth system data for the influence of feedback processes.

Context for Use

This unit should ideally occur mid-course, after students have been introduced to systems thinking concepts in Units 1 and 2, and system modeling in Unit 3. Unit 4 uses a dynamical system model developed with the STELLA software package, and instructors have the same approaches for model access and use as in Unit 3.

This unit may fit into a single 50-minute class period if the instructor and students are already familiar with model usage from Unit 3. Alternatively, all graphs and model output necessary for Unit 4 are provided if the instructor wishes to present information. There are several opportunities throughout the unit to explore data and system relationships further, which would entail two or more class periods.

Description and Teaching Materials

If instructors choose to use STELLA software, there are different options available depending on classroom setting, platform, and financial considerations.

- Download and install the ***free*** isee Player software available in Windows and Macintosh versions. Models can be run and output interpreted with Player. *Units 3 and 4 can be completed with Player software alone.*
- Purchase, download, and install STELLA software available in Windows and Macintosh versions. Models can be run and output interpreted with STELLA; models can also be modified, output saved, and shared with STELLA.
- Purchase, download, and install the STELLA Modeler for iPad software (also available from the Apple App Store). Models can be run and output interpreted with Modeler for iPad; models can also be modified, output saved, and shared with Modeler for iPad.

Students will need to complete the Systems modeling feedback worksheet Word doc (Microsoft Word 75kB Sep14 16) (also available as a PDF (Acrobat (PDF) 77kB Sep14 16)), which can be done electronically or as a handout.

The Systems modeling feedback quick start PowerPoint (PowerPoint 639kB Jan4 17) (also available as a PDF (Acrobat (PDF) 536kB Jan4 17)) has instructions on how to get started using Unit 4 models. If students will be using Player or STELLA software, they should download the software (if they did not already do so in Unit 3) and review the quick start prior to class.

**Note that the STELLA model and model images used in this unit were created with STELLA v. 10 software.*

Part 1. Pre-experiment discussion — Feedbacks in a system (5–10 min)

Begin class with an instructor-led review of systems concepts covered in Unit 1 and 2, namely negative (balancing) and positive (reinforcing) feedbacks. Next, discuss how feedbacks are implemented in systems models using the Systems modeling feedback PowerPoint presentation (PowerPoint 568kB Sep14 16) (also available as a PDF (Acrobat (PDF) 621kB Sep14 16)).

Part 2. Experiment 1 — Negative feedbacks in a system (20 min)

- Students should use the Systems modeling feedback worksheet Word doc (Microsoft Word 75kB Sep14 16) (also available as a PDF (Acrobat (PDF) 77kB Sep14 16)) to walk through the experiment. Ideally this would be done in small groups, so that students can work together to answer questions about model output.
    - Experiment 1a: Run Bathtub feedback model_Exp1 (Stella Model (v10 .stmx) 8kB Jan4 17) with the Water in bathtub = 10 liters*;* Discuss results, namely that when inflow and outflow fluxes are balanced, even with feedback loop in place, the reservoir size does not change with time. Hence, the system is in equilibrium.

    - Experiment 1b: Run Bathtub feedback model_Exp1 (Stella Model (v10 .stmx) 8kB Jan4 17) with the Water in bathtub = 15 liters; Discuss results, where inflow and outflow fluxes are not balanced. The reservoir size and drain rate change with time, until system returns to equilibrium.
    - Experiment 1c: Run Bathtub feedback model_Exp1 (Stella Model (v10 .stmx) 8kB Jan4 17) with the Water in bathtub = 5 liters; Discuss results, where inflow and outflow fluxes are again not balanced. The reservoir size and drain rate change with time, until system returns to equilibrium.
- The instructor should encourage whole class discussion of findings. Model images and discussion notes for instructors are in the ▶ Systems modeling feedback experiment notes PowerPoint -- private instructor-only file
  Systems modeling feedback experiment notes PowerPoint

  This file is only accessible to verified educators. If you are a teacher or faculty member and would like access to this file please enter your email address to be verified as belonging to an educator.

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  PDF

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Part 3. Experiment 2 — Positive feedbacks in a system (20 min)

- Students should use the Systems modeling feedback worksheet Word doc (Microsoft Word 75kB Sep14 16) (also available as a PDF (Acrobat (PDF) 77kB Sep14 16)) to walk through the experiment. Ideally this would be done in small groups, so that students can work together to answer questions about model output.
    - Experiment 2a: Run Bathtub feedback model_Exp2 (Stella Model (v10 .stmx) 5kB Jun21 16) with Water in bathtub = 10 liters; Observe and discuss that system is in equilibrium, even with positive feedback structure.
    - Experiment 2b: Run Bathtub feedback model_Exp2 (Stella Model (v10 .stmx) 5kB Jun21 16) with Water in bathtub = 15 liters; Observe and discuss results, noting runaway growth and exponential change.
    - Experiment 2c: Run Bathtub feedback model_Exp2 (Stella Model (v10 .stmx) 5kB Jun21 16) with Water in bathtub = 5 liters; Observe and discuss results, noting threshold behavior and system crash.
- The instructor can encourage whole class discussion of findings. Model images and discussion notes for instructors are in the ▶ Systems modeling feedback

experiment notes PowerPoint -- private instructor-only file
Systems modeling feedback experiment notes PowerPoint

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). The instructor can also encourage students to vary the Water in Bathtub value repeatedly, noting that any initial Water in Bathtub value other than 10 results in runaway behavior.

Part 4. Homework

- As a summative assessment, in the Systems modeling feedback homework (Microsoft Word 58kB Sep14 16) (also available as a PDF (Acrobat (PDF) 126kB Sep14 16)), students examine Arctic Sept. sea ice data (Excel 36kB Jun21 16) from 1979–2015 and apply system diagram/modeling and feedback concepts.

Teaching Notes and Tips

While Unit 4 can be done with model images alone, we highly recommend using the models interactively in class — the models can be run repeatedly to reinforce concepts, and the instructor (and students) can easily and quickly navigate between different model levels (e.g., interface and model levels).

If students will use models in class, they should have the software installed and models downloaded prior to class. They should also use the Systems modeling feedback quick start PowerPoint (PowerPoint 639kB Jan4 17) (also available as a PDF (Acrobat (PDF) 536kB Jan4 17)) to become familiar with basic model controls prior to class.

The homework assignment asks students to create a 36-year (1979–2015) time series plot of Arctic sea ice data, using Excel or similar software. If instructors wish to forgo this part of the homework, the data are plotted here for students to use: Arctic sea ice plot (Acrobat (PDF) 132kB Jul6 16). The data set and plot can be updated as new data become available by visiting the National Snow and Ice Data Center website.

Assessment

To assess student comprehension during the unit, instructors can collect the Systems modeling feedback worksheet Word doc (Microsoft Word 75kB Sep14 16)] (also available as a PDF (Acrobat (PDF) 77kB Sep14 16)) after class. An answer key is provided here in

▶ Word -- private instructor-only file
Word

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The Systems modeling feedback homework Word doc (Microsoft Word 58kB Sep14 16) (also available as a PDF (Acrobat (PDF) 126kB Sep14 16)) assignment provides an opportunity to assess whether students have developed a basic understanding of feedbacks in systems diagrams and models, and the impact of feedbacks on Earth system processes. An answer key is provided here in

▶ Word -- private instructor-only file
Word

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. A suggested rubric for grading the homework is available in Word -- private instructor-only file
Word

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References and Resources

Additional information about feedback loops

- Introductory material on feedback loops from *Starting Point*
- Discussion of negative feedback loops, and possible alternative naming from the Earth and Mind Blog

Activities that feature threshold behavior and tipping points

- In ecosystems: Calculating Resilience, Tipping Points, and Restoration for Lakes at Risk from Acid Rain activity by Bill Stigliani, University of Northern Iowa
- In lakes: The Story of Big Moose Lake: Resilience, Tipping Point, and Restoration case study by Bill Stigliani, University of Northern Iowa

Arctic sea ice

- Arctic sea ice news and analysis from the National Snow and Ice Data Center
- Satellite observations of Arctic sea ice from NSIDC

- Visualization of Arctic sea ice extent, 1979-2014 YouTube video
- Snow/ice albedo chapter from the Earth Exploration Toolbook
- User-based analysis of sea ice time series using the Climate Reanalyzer tool
- Climate Reanalyzer animation of Northern Hemisphere sea ice and snow cover, 1979-2000
- Reading: Stroeve, J.C., et al., 2012. The Arctic's rapidly shrinking sea ice cover: A research synthesis, *Climate Change*, 110 (3-4), 1005–1027.

Teaching Themes

- Systems Thinking »
- Temporal Reasoning »
- Geoscience Methods »
- Authentic Data »

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Unit 5: Analyzing Complexity

Deborah Gross (Carleton College), Lisa Gilbert (Williams College), and Karl Kreutz (University of Maine)
Author Profiles
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Profile Lisa Gilbert, Williams College
Profile Karl Kreutz, University of Maine

These materials have been reviewed for their alignment with the Next Generation Science Standards as detailed below. Visit InTeGrate and the NGSS to learn more.

Overview

Students revise their systems diagrams from Unit 2, based on their expanded knowledge of that system and experience with systems thinking.

Science and Engineering Practices

Developing and Using Models: Evaluate limitations of a model for a proposed object or tool. MS-P2.1:

Developing and Using Models: Develop or modify a model— based on evidence – to match what happens if a variable or component of a system is changed. MS-P2.2:

Developing and Using Models: Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. MS-P2.4:

Developing and Using Models: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system HS-P2.3:

Developing and Using Models: Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. HS-P2.6:

Cross Cutting Concepts

Systems and System Models: Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. MS-C4.1:

Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. MS-C4.2:

Systems and System Models: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. HS-C4.2:

Systems and System Models: Systems can be designed to do specific tasks. HS-C4.1:

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-C4.3:

Stability and Change: Systems can be designed for greater or lesser stability. HS-C7.4:

Stability and Change: Much of science deals with constructing explanations of how things change and how they remain stable. HS-C7.1:

Stability and Change: Feedback (negative or positive) can stabilize or destabilize a system. HS-C7.3:

Disciplinary Core Ideas

Earth Materials and Systems: Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. HS-ESS2.A1:

1. **This material was developed and reviewed through the InTeGrate curricular materials development process.** This rigorous, structured process includes:

    - team-based development to ensure materials are appropriate across multiple educational settings.
    - multiple iterative reviews and feedback cycles through the course of material development with input to the authoring team from both project editors and an external assessment team.
    - real in-class testing of materials in at least 3 institutions with external review of student assessment data.
    - multiple reviews to ensure the materials meet the InTeGrate materials rubric which codifies best practices in curricular development, student assessment and pedagogic techniques.
    - review by external experts for accuracy of the science content.

2. **This activity was selected for the On the Cutting Edge Reviewed Teaching Collection**

    This activity has received positive reviews in a peer review process involving five review categories. The five categories included in the process are

- Scientific Accuracy
- Alignment of Learning Goals, Activities, and Assessments
- Pedagogic Effectiveness
- Robustness (usability and dependability of all components)
- Completeness of the ActivitySheet web page

For more information about the peer review process itself, please see https://serc.carleton.edu/teachearth/activity_review.html.

This page first made public: Oct 24, 2016

Summary

This unit has students build on a system diagram, to include new knowledge about quantitative values and relationships. They will also write about and discuss what they know about their systems, the questions that still remain, and how to find answers to their questions.

Learning Goals

Used this activity? Share your experiences and modifications

- Students will describe quantitative relationships among components of a complex system.
- Students will sketch graphs of the behavior of measurable quantities in their system as a function of time.
- Students will discuss with their peers their current level of knowledge about the components of a systems diagram.
- Students will write about the components of a systems diagram in an optional homework assignment.

Context for Use

This lesson should occur at a point in a course when students know enough information to look at a system diagram with some quantitative understanding of the processes within it. This will allow them to use skills developed with STELLA models in Units 3 and 4 in an application directly relevant to their course. If Units 3 and/or 4 are not used in the course, this exercise can follow directly from Unit 2 or be used alone. This unit is designed to include class discussion, in-class activities, and an optional homework assignment that involves writing about complex systems.

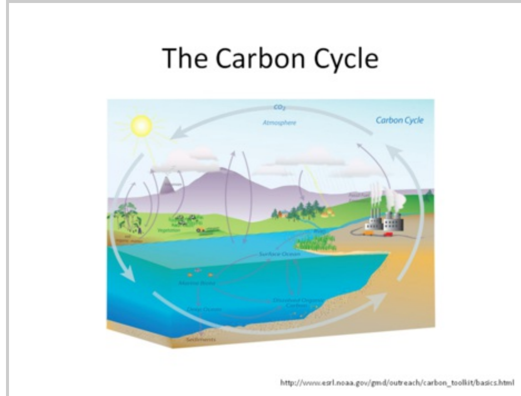
Description and Teaching Materials

To carry out these activities students will need:

- This handout of The Carbon Cycle (available as a PDF (Acrobat (PDF) 175kB Jun21 16) or PowerPoint slide (PowerPoint 2007 (.pptx) 233kB Jun21 16)), their original systems diagram created in Unit 2, or any other systems diagram of the instructor's choice

- Blank half-sheets of paper

The first goal of this unit is to encourage students to think about the items which they designate as "quantifiable" in a system diagram and to predict the form of the measured quantity, as a value (flux/rate or quantity in a reservoir) or as a graph of value versus time. Doing this will require bringing in outside knowledge about the components of a system, and the level of detail desired for this will depend on the instructor's course goals.



The Carbon Cycle diagram

Part 1. Discussion of a Complex System and Quantifiable Components (10 min)

The instructor will provide the students with a diagram of The Carbon Cycle and will lead a discussion about specific content within the diagram related to the course. Examples of data for many quantifiable fluxes and reservoir amounts are provided (Carbon Cycle Quantities PDF (Acrobat (PDF) 666kB Jul24 20) or PowerPoint slide (PowerPoint 2007 (.pptx) 855kB Jul24 20)), and those which do not directly measure carbon can be converted into carbon fluxes or reservoirs when combined with measurements of, for example, carbon concentrations in reservoirs. If the students have done Unit 2, labeling values for which quantitative information can be obtained will be review. If the class has included discussions or activities related to quantitative information in a systems diagram, this portion may be skipped.

Part 2. Addition of Quantifiable Data to Original Systems Diagrams (20 min)

Students should be organized into groups of 3–5 people. If they did Unit 2, these can be the same groups. The groups should be given at least five half-sheets of blank paper.

Student groups are asked to identify a small number of quantifiable items in the diagram of The Carbon Cycle and describe them quantitatively (fluxes or rates) and/or graphically (for values that change with time), with appropriate units. Students should quantify at least one flux/rate, at least one reservoir, and at least one variable that changes with time. Groups should sketch graphs on pieces of paper and attach them to their system diagrams. The level of quantitative detail requested of the students will vary depending on the instructor's goals for the course. If the students do not have the content knowledge to generate absolute numbers, they can be asked to propose relative values or sketch trends graphically but without numerical values.

For a more advanced activity, this task can be expanded to include a pre-activity homework or in-class assignment for students to find relevant data sets to use in developing these values and graphs.

Students will then do a very brief "gallery walk" where they look at all or a subset of the graphs sketched by other groups. Students will reconvene with their groups at their own diagram and add to it anything that they saw in the other diagrams that they think is critical to include, but which they had missed. Students should photograph their graphs and, if possible, upload their photographs to an online space (course management system, etc.) so that there is a permanent record of them.

Part 3. Brainstorming About Sources of Information and Knowledge (20 min)

This activity allows students to explore the ideas that they have been working with in their groups, and simultaneously prepare for the optional homework assignment described in Part 4. In addition, it provides an opportunity for students to connect the concepts they have explored in the system diagram with experiences from outside of the course. If the homework will be assigned, the text of the homework assignment should be available to students at this time, either as a handout or electronically, so that the students see the questions that they will be asked to address. A template for a handout describing the homework is provided in Part 4, below.

Students should continue to work with their groups for a small-group discussion that will allow them to brainstorm about ways to fill in the gaps in their system diagram and gain further knowledge. Students should categorize and explore how to answer questions that they have about the source(s) of the knowledge that goes into making The Carbon Cycle diagram quantitative. The assignment does not include answering the questions they pose, but that could be added by the instructor if desired, in an expanded homework assignment.

Guided by the discussion handout (Discussion Handout PDF (Acrobat (PDF) 85kB Sep14 16) or Word doc (Microsoft Word 2007 (.docx) 20kB Sep14 16)), the members of the groups should identify two questions that they have about the content of The Carbon Cycle diagram. They should focus on the topics they feel least secure about, and the type of knowledge that would be necessary to gain to become more secure (questions 4 and 5 in the optional homework described in Part 4). They should sort their questions/answers into the following categories:

- Those that can be answered by another member of the group.
- Those which can be answered within the context of this course, either from past or anticipated future classes.
- Those which can be answered by taking a specific course about which the students are aware.
- Those which can only be answered by researching the primary literature.
- Other, including specific topics designated by the instructor or those which do not easily fit into a defined category.

The students should designate one group member to be a note-taker and one group member to report out into a subsequent larger group discussion. The instructor should provide a printed copy of the discussion sheet to each member of the group, with an additional sheet for each group that the designated note-taker can submit at the end. After the groups spend about 10 minutes working together on their questions, the instructor should facilitate a discussion (~10 minutes) that either includes the whole class or subsets of the class. In this discussion, the instructor should ask students to share their results from categorizing their thoughts in the above exercise, by posing any or all of the following discussion questions:

- What understanding of The Carbon Cycle do you gain from using the systems diagram that you would not get by looking only at individual relationships within the system?

- Which discipline or disciplines contribute the most to your current understanding of The Carbon Cycle, and which one(s) will be most instrumental in helping to increase your understanding of it?
- How has your understanding of The Carbon Cycle grown or changed by labeling components and/or by including quantitative measures of reservoirs, fluxes, and/or values that change with time?
- Would the use of a system diagram such as The Carbon Cycle Diagram help you address questions about the impact of a change in policy, and thus human activity, on The Carbon Cycle? For example, what would happen if coal-fired power plants were suddenly banned, or if regulations on fisheries were suddenly lifted?

As desired by the instructor, the students can be asked to address any of the topics identified within the system diagram, or the questions above, with further research.

Part 4. Writing About the Quantitative Aspects of the Complex System (Optional Homework)

As a summative assessment after Unit 5, students will individually write a two- to three-page narrative description of The Carbon Cycle diagram, describing the same five topics discussed in the homework assigned in Unit 2, but with emphasis on the quantitative aspects of the diagram which they have recently engaged with:

1. The components of the diagram.
2. The connections between components of the diagram. The students should use correct terminology throughout the discussion.
3. The areas of their diagram which they feel most secure about (i.e. which do a good job of representing what they are trying to represent).
4. The areas of their diagram which they feel least secure about (i.e. which do a poor job of representing what they are trying to represent or which they do not fully understand). There should be at least five specific areas identified in this section.
5. The type of knowledge they believe would be necessary to gain to be able to improve the areas of the diagram they are least secure about, and some thoughts about who generates this type of knowledge (i.e. geologist, chemist, political scientist, etc.).

A template for a student handout for the homework assignment is provided here (Writing About Complexity Assignment PDF (Acrobat (PDF) 88kB Oct17 16) or Word doc (Microsoft Word 2007 (.docx) 18kB Oct17 16)). This assignment sheet includes a rubric for evaluating the students' work; the rubric is given to them to guide their writing.

Teaching Notes and Tips

Choice of System Diagram For This Unit: This unit is described above with The Carbon Cycle as the central system diagram, however there are various options for carrying out this unit:

- **Option 1**: Use The Carbon Cycle, as described above.
- **Option 2**: Use The Whale Pump or The Cryosphere diagrams, examples of which are provided in the presentation created for Unit 2 (How to Label a System Diagram PDF (Acrobat (PDF) 789kB Oct17 16) or as a PowerPoint slide (PowerPoint 2007 (.pptx) 823kB Oct17 16)). Note that these examples include information about variables which can be quantified, but rates/fluxes and examples of measurable quantities as a function of time are not provided.
- **Option 3**: If the class has done Unit 2, have the students use the system diagram that they drew in Unit 2 as the diagram for this unit. This will require retrieving their submitted system diagram from Unit 2 as a starting point
- **Option 4**: Use any other system diagram that is relevant to the course.

If the class has done Unit 2, Option 3 is recommended, but any of these options will be appropriate. If a system diagram other than The Carbon Cycle is used, just replace "The Carbon Cycle" in the activities and handouts with the appropriate name.

Group Work: This unit suggests that students reform the groups that they were in when they drew and worked with systems diagrams. If the instructor did not do Unit 2, or if course enrollment has changed significantly, groups should be created such that all students are in groups of 3–5 students. For the larger group discussion, larger classes can be broken up into subsets, or, in smaller classes, the whole class can discuss together. The goal is to have students articulate their answers to others and to hear from other groups.

Gallery Walk: A gallery walk provides an opportunity for students to circulate through the room and look at the products of the other groups' efforts; in this unit, Part 2, the products are posters containing system diagrams that now have graphs attached to them showing how one or more quantities change with time. More information about how to implement Gallery Walk activities is available, although in this version of the activity, no questions are posted around the room — students are instead asked to look at and evaluate the components included by their peers as they evaluate the completeness of their own diagrams, providing them input for revision. If time is a constraint or if there are many groups, each student in a group can be asked to look at three different diagrams from other groups, ensuring that the members of a group have sampled multiple other diagrams.

Assessment

A suggested rubric for assessment of student essays is provided here (Writing About Complexity Rubric PDF (Acrobat (PDF) 66kB Oct17 16) or Word doc (Microsoft Word 2007 (.docx) 16kB Oct17 16)), and is provided for the students on the homework assignment handout that is given in Part 4. The homework assignment provides an opportunity to assess whether students are appropriately using terminology, identifying measurable quantities in a system diagram, and thinking about how to obtain the quantitative information necessary to transform a diagram into a model. Students who meet the "Acceptable" or "Exemplary" criteria in most of the categories demonstrate good mastery of the ability to think about how to take a system diagram to a more quantitative level. Students can be asked to self-evaluate their work using the rubric or can be organized into peer-review teams to evaluate each others' work using the rubric, in addition to the instructor grading the work.

References and Resources

Carbon Cycle Example:

Data for the quantitative relationships in the carbon cycle can be found in the Chapter 6 of *Climate Change 2013: The Physical Science Basis*, from the Intergovernmental Panel on Climate Change (IPCC):

Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quéré, R.B. Myneni, S. Piao and P. Thornton, 2013: Carbon and Other Biogeochemical Cycles. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. (Link to the full report is here: http://www.ipcc.ch/report/ar5/wg1/)

Teaching Themes

- Systems Thinking »
- Interdisciplinary Teaching »

Unit 6: Systems Thinking Synthesis

Lisa Gilbert (Williams College), Karl Kreutz (University of Maine), and Deborah Gross (Carleton College)
Author Profiles
Profile Lisa Gilbert, Williams College

Profile deborah gross, Carleton College

Profile Karl Kreutz, University of Maine

These materials have been reviewed for their alignment with the Next Generation Science Standards as detailed below. Visit InTeGrate and the NGSS to learn more.

Overview

Students quiz each other on course material and then find authentic (and often creative) connections between seemingly disparate topics in the course. This approach challenges students to use holistic thinking when reviewing, and can be readily customized for any course.

Science and Engineering Practices

Engaging in Argument from Evidence: Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. MS-P7.1:

Cross Cutting Concepts

Systems and System Models: Models are limited in that they only represent certain aspects of the system under study. MS-C4.3:

Systems and System Models: Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. MS-C4.1:

Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. MS-C4.2:

Systems and System Models: Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. HS-C4.4:

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-C4.3:

1. **This material was developed and reviewed through the InTeGrate curricular materials development process.** This rigorous, structured process includes:
    - team-based development to ensure materials are appropriate across multiple educational settings.
    - multiple iterative reviews and feedback cycles through the course of material development with input to the authoring team from both project editors and an external assessment team.
    - real in-class testing of materials in at least 3 institutions with external review of student assessment data.
    - multiple reviews to ensure the materials meet the InTeGrate materials rubric which codifies best practices in curricular development, student assessment and pedagogic techniques.
    - review by external experts for accuracy of the science content.
2. **This activity was selected for the On the Cutting Edge Exemplary Teaching Collection**

    Resources in this top level collection a) must have scored Exemplary or Very Good in all five review categories, and must also rate as “Exemplary” in at least three of the five categories. The five categories included in the peer review process are

    - Scientific Accuracy
    - Alignment of Learning Goals, Activities, and Assessments
    - Pedagogic Effectiveness
    - Robustness (usability and dependability of all components)
    - Completeness of the ActivitySheet web page

    For more information about the peer review process itself, please see https://serc.carleton.edu/teachearth/activity_review.html.

This page first made public: Oct 24, 2016

Summary

This in-class exercise is an alternative to standard review sessions and models the systems thinking students need to do when working on complex, interdisciplinary issues. Students quiz each other on course material and then find authentic (and often creative) connections between seemingly disparate topics in the course. This approach challenges students to use holistic thinking when reviewing, and can be readily

customized for any course.

Learning Goals

Used this activity? Share your experiences and modifications

Students will be able to explain complex and nuanced connections between seemingly unrelated topics in the course.

Context for Use

This exercise works well at the end of a course, as an alternative to standard review sessions, with or without any prior discussion of systems thinking. The exercise can be used for any course in any field, at any level, although the assessment and rubric are aimed at introductory to intermediate undergraduate courses in the sciences.

Students working on Synthesis Activity on the last day of class.

Description and Teaching Materials

Preparation: The instructor should start by generating a list of approximately 10 (or more) review-type questions that represent the breath of material covered. To each question attach a related process, overarching theme, or syllabus topic. Use the list of questions and associated topics to replace the questions and topics in the student handout Student Handout for Synthesis Excercise (Microsoft Word 2007 (.docx) 79kB Sep14 16) or PDF version (Acrobat (PDF) 77kB Sep14 16). The example is from an oceanography course, and follows the course syllabus closely Sample syllabus from Oceanography Course (Microsoft Word 2007 (.docx) 195kB Jul17 15).

Part 1. Review and discussion connections in pairs. (20–40 min)

- Each student in the class receives a sheet with an instructor-generated question and related topic Student Handout for Synthesis Excercise (Microsoft Word 2007 (.docx) 79kB Sep14 16) or PDF version (Acrobat (PDF) 77kB Sep14 16) .
- Review the directions at the top (3–5 min) and model how to do the exercise in pairs (Student A and Student B), following the instructions on the sheet.

Student A. Question: What drives convection in the (a) mantle, (b) ocean, and (c) atmosphere? Topic: convection.

Student B. Question: Where do the major dissolved components of seawater come from, and how do we know the salinity of the ocean has been relatively stable over the last 1.5 Ga? Topic: residence time.

1. Pose the question on your sheet to your partner. Listen to the answer and give oral feedback. Nothing is written.

2. Hear your partner's question, give your best answer, and get feedback.

Nothing is written.

3. Work together to find a connection between the **topics** listed at the top of each of your sheets (not the specific questions), and write out connections on your own sheet.

4. Find a new partner and go back to Step 1.

- The instructor can use a bell or timer (or just an oral warning) to tell students when to rotate to a new partner. The instructor should give the first pairing about 7 minutes. Then, 5 minutes thereafter. In a small class, the instructor can move through all the groups in the first round or two answering questions about the process. If the class is struggling, an instructor could stop the group after the first pairing for any questions.
- After 3–5 rounds of pairings for as much time is available (minimum of 20 to maximum of 40 minutes), the instructor stops the group.

Part 2. Group discussion. (10 min)

Instructor poses the question on the board:

What are two topics you thought were especially difficult to connect?

- The instructor writes the topics on the board and students volunteer creative connections, which are also written on the board.
- After about three pairs, the instructor challenges the class to find a topic from the course that no one else can convincingly connect to the topics already listed. These new topics are listed on the board and students volunteer connections.

Part 3. Review advice. (5 min or homework, optional)

At the end of class, the instructor poses two to three challenges to students as they review course material, or hands out this homework Synthesis Exercise Reflection (Microsoft Word 2007 (.docx) 45kB Sep14 16) or PDF version (Acrobat (PDF) 25kB Sep14 16):

1. Search for themes that connect many topics (e.g., density, drivers of ocean change, etc.)
2. Which of the topics you listed either cannot be influenced by society nor influence society in any way?
    - Short answer: none.
3. (optional) List connections to something you learned outside this course this semester (another course this term or in the past from outside this discipline, current event in the news, etc.).

Teaching Notes and Tips

Part 1.

Modeling the exercise with a TA or student may clarify many of the questions that arise.

For the first round, the instructor and TA(s), if available, should briefly check in with as many groups as possible to make sure they understand what to do.

When 5 minutes remain for Part 1, the instructor can call out "last pairing" and direct students who finish before 5 minutes to the full list of questions and topics on the back of their sheet. Students generally proceed quickly to quietly reading this study guide, which makes it easier to call time for the group discussion.

For large classes, multiple students will get the same sheet, but as long as there are about 10 unique sheets, students should not have trouble finding 3–6 different pairings.

Alternative approach: either in class (before the Synthesis class) or as homework, have students write their own review questions. Use the student-generated questions to generate the student handouts.

Parts 2 and 3.

For Part 2 , students can be encouraged take out their syllabus to locate additional topics quickly. Parts 2 and 3 can be combined into a single instructor-led discussion. An instructor can draw connections between topics quickly and point out additional connections as the diagram is made, and encourage students to continue part of their review by making their own diagram in this fashion.

Assessment

This unit is assessed with a broad synthesis question on a final exam or as a take-home writing assignment. As an exam question, completion time is about 20 minutes. In the question below substitute"ocean" for "Earth" or "climate" or other more relevant term for the course.

> Imagine it is some months from now and you have applied for a job as an ocean science writer for a new popular science magazine called *Our Changing Ocean*. In the interview, the editor asks you:
>
> "People say 'everything is connected,' but I rarely get specific examples. Will you convince me of the connectedness and complexity of the ocean?"
>
> Write what you would say in response by picking any three seemingly unrelated concepts from this course and relating them in the the context of human interaction with the ocean. Be sure to use systems thinking language and specific examples.

Rubric

Topics seemingly unrelated?

- 0=not at all
- 1=somewhat; e.g., two of the topics presented in class the same day
- 2=yes; e.g., sperm whales, forest fires in Minnesota, and Arctic sea ice extent

Accuracy (of descriptions and connections)?

- 0=not at all
- 1=somewhat; e.g., more than one minor incorrect detail
- 2=yes

Convincing connections?

- 0=not at all
- 1=somewhat; e.g., some connections silly or superficial
- 2=yes; using a diagram or words

Connections show complexity?

- 0=not at all
- 1=somewhat; e.g., incomplete understanding of feedback
- 2=yes; using a diagram or words

Relevant to "ocean change"?

- 0=not relevant
- 1=somewhat; e.g., alluded to but not mentioned explicitly
- 2=yes, directly addressed

Specific examples?

- 0=no
- 1=some; e.g., mentions specific places, but insufficient detail for a Scientific American-type article
- 2=yes

Writing clear and organized?

- 0=no, very difficult to follow
- 1=somewhat; e.g., lacking summary/overview or other structure, but reader can still follow with some effort
- 2=yes, considering time allotted

Score out of 14 points.

Alternative Assessment. This exam question or writing assignment addresses how thinking about a problem from a systems perspective leads to more nuanced conclusions than considering just individual parts or a single cause-effect relationship. Student handout (Microsoft Word 2007 (.docx) 127kB Sep14 16) (PDF version). (Acrobat (PDF) 105kB Sep14 16)

Instructor version with sample answer -- private instructor-only file
Instructor version with sample answer

This file is only accessible to verified educators. If you are a teacher or faculty member and would like access to this file please enter your email address to be verified as belonging to an educator.

Email Adress Submit

(PDF version). -- private instructor-only file
(PDF version).

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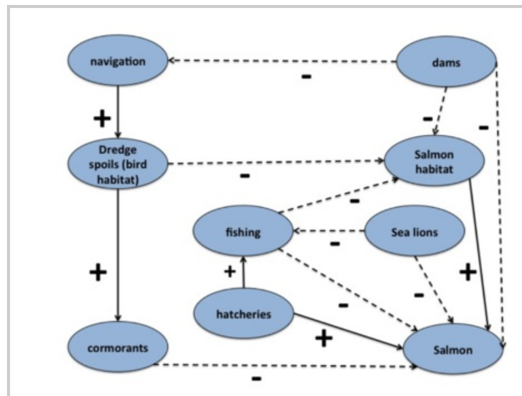

- You have been selected to speak to your town council on the issue of cormorant hunting.
  - The first speaker states the cause-effect relationship plainly: cormorants are eating salmon, therefore we have to remove cormorants.
  - Now it is your turn. How would showing a systems diagram like the one shown here make your policy recommendations different from that of the first speaker?
  - A full-credit answer is (1) logical, (2) clear, and (3) makes reference to complexity/nuance, especially the importance of environmental policy decisions being made based on more than a simple cause-effect relationship.

References and Resources

Hiller Connell, K.Y. et al., 2012. Assessing Systems Thinking Skills in Two Undergraduate Sustainability Courses: A Comparison of Teaching Strategies.

Teaching Themes

- Systems Thinking »
- Real-World Connections »
- Interdisciplinary Teaching »

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Assessment of Module Goals

Below, you will find a list of assessments for each unit of the module, as well as assessments for the module as a whole. Each unit has associated with it formative and/or summative assessments to measure student progress toward individual unit learning outcomes. We also identify the unit assessments which specifically ask students to reflect on their their own learning by indicating that they address metacognition. To assess overall learning in this module, you will find a summative assessment question directly related to the overriding module goal of increasing students' abilities to think about complex systems from a systems perspective. This question directly assesses how well students can integrate difficult-to-connect ideas using this approach.

Overall Module Assessments

Summative Assessment

This broad synthesis question can be used on a final exam or as a take-home writing assignment. As an exam question, completion time is about 20 minutes. In the question below substitute "ocean" for "Earth" or "climate" or other more relevant term for the course.

> Imagine it is some months from now and you have applied for a job as an ocean science writer for a new popular science magazine called *Our Changing Ocean*. In the interview, the Editor asks you:
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Score out of 14 points.

Unit Assessments

List of Assessments by Unit:

The assessments used in each unit are listed below, along with the module goals which they assess. Note: Rubrics for these unit assessments are presented on the individual unit pages.

Unit 1 Assessments:

- Knowledge survey handout (Microsoft Word 2007 (.docx) 60kB Sep10 16). Addresses: Module goal 3 and metacognition.

- Reflection handout (see last question) (Microsoft Word 2007 (.docx) 60kB Sep10 16). Addresses: Metacognition.
- MPR Radio Piece/System Diagram Student Handout for Evaluating a System Diagram Activity (Microsoft Word 2007 (.docx) 97kB Jul15 15) or PDF version (Acrobat (PDF) 69kB Jul5 16). Addresses: Module goals 1–3.

Unit 2 Assessments:

- Draw a System Diagram (Acrobat (PDF) 51kB Sep11 16). Addresses: Module goals 1–3.
- Picturing a Complex System Assignment -- private instructor-only file

  Picturing a Complex System Assignment

  This file is only accessible to verified educators. If you are a teacher or faculty member and would like access to this file please enter your email address to be verified as belonging to an educator.

  Email Adress [ ] Submit

  . Addresses: Module goals 1–3.

Unit 3 Assessments:

- Systems modeling worksheet (Microsoft Word 80kB Sep12 16), equilibrium and residence time. Addresses: Module goals 1–3 and metacognition.
- Systems modeling homework (Microsoft Word 43kB Sep12 16), equilibrium and residence time. Addresses: Module goals 1–3.

Unit 4 Assessments:

- Systems modeling feedback worksheet (Microsoft Word 75kB Sep14 16). Addresses: Module goals 1–3 and metacognition.
- Systems modeling feedback homework (Microsoft Word 58kB Sep14 16). Addresses: Module goals 1–3.

Unit 5 Assessments:

- Inclusion of quantifiable data in system diagram. Addresses: Module goals 1–3.
- Writing About Complexity Assignment (Acrobat (PDF) 88kB Oct17 16). Addresses: Module goals 2 and 3.

Unit 6 Assessments:

- Synthesis exercise reflection Synthesis Exercise Reflection (Microsoft Word 2007 (.docx) 45kB Sep14 16) or PDF version (Acrobat (PDF) 25kB Sep14 16). Addresses: Module goals 1 and 3 and metacognition
- Summative assessment and rubric (Microsoft Word 2007 (.docx) 73kB Jul5 16). Addresses: Module goal 3.

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Instructor Stories and Adaptations

These resources describe how the module was adapted for use in different settings. We hope these stories inspire your own use of the module and give you insight into how to adapt the materials for your classroom.

Lisa Gilbert: Systems Thinking at Williams-Mystic. In the spring of 2016, the Systems Thinking Module was used in Oceanographic Processes, a small intermediate-level course at The Maritime Studies Program of Williams College and Mystic Seaport (Williams-Mystic). The course is part of an interdisciplinary maritime studies "study away" semester at Williams-Mystic, with mostly third-year undergraduates from a variety of colleges and universities. Students represented every possible major, from computer science to theater arts to environmental history. The class met two times a week for 75 minutes (plus 3.5-hour labs and extended field seminars). Students completed the module during portions of five of our class meetings spread throughout the semester.

Deborah Gross: Systems Thinking at Carleton College In Fall 2015, the Systems Thinking Module provided a backbone for ENTS 287, Climate Science at Carleton College. This course is intermediate-level, requiring students to have taken one science or math course prior to enrolling, and is taken by students from a range of majors, including natural sciences, environmental studies, and others. The class met three times a week, with two 70-minute meetings and one 60-minute meeting. There was no associated lab with this course. Students completed the Systems Thinking module, including all optional components, during six class meetings spread throughout the term (the first two right at the beginning, Units 3–5 just after mid-term, and Unit 6 as a culminating activity on the last day of the course).

Karl Kreutz: Systems Thinking at the University of Maine The Systems Thinking Module was used in ERS201: Global Environmental Change during the Spring 2016 semester. This small intermediate-level course is part of a two-semester sequence designed for new Earth and Climate Science majors, and usually has a diverse enrollment including a range of natural and social science majors. The class met two times a week for 75 minutes, plus in a 3-hour lab once a week. Students completed the Systems Thinking module during six class meetings spread across the semester.

Additional Instructor Stories

Skip to search results Skip to pagination

Molly Redmond: Using InTeGrate Materials in Biology 3144 (Ecology) at UNC Charlotte
Molly Redmond, University of North Carolina at Charlotte
Teaching the Carbon Cycle, Climate Change, and Feedback Loops in Introductory Ecology I used material from the Carbon, Climate and Energy Resources Module and the Changing Biosphere Module, along with some inspiration from the Systems Thinking Module, in my intro Ecology class. This a required core class for Biology majors at UNCC and consists largely of juniors and seniors, but most students have little to no background in environmental science or ecology. I taught two sections of this class, each section had 76 students and met twice a week for 75 minutes. I did the activities in both sections. Our classroom was designed for active learning, with 76 desks on wheels. These desks can face forward during the lecture portion of the class or be moved into groups for activities. This flexible arrangement works very well for my class, which is mix of traditional lecture, frequent clicker questions, and longer group activities. The room has five projectors, so students can see slides on all walls of the room. The one downside is that the room is so full of desks, it's challenging for me to move around the classroom and nearly impossible for the students to move around out of their desks. I modified the InTeGrate materials to suit the physical structure of the classroom and my relatively large (but not huge) classes.

Also Related to Systems Thinking

Skip to search results Skip to pagination

Pathways to performance expectations using InTeGrate materials
Nov 15 2018 Thursday, November 15, 2018 11:00 am PT | 12:00 pm MT | 1:00 pm CT | 2:00 pm ET Presenters: Anne Egger (Central Washington University), Kathryn Baldwin (Eastern Washington University), and Lisa Gilbert (Williams ...

InTeGrate 101: How to incorporate InTeGrate classroom materials into your courses
Dec 8 2017 In this free, one-hour webinar participants will be introduced to the large collection of InTeGrate teaching materials and provided with strategies to incorporate activities into their own college classrooms. These data-rich activities provide up front learning outcomes, embedded assessment tools, and instructor stories from a variety of institution types. Following a brief overview of how the InTeGrate materials were designed, we will navigate through the online collection and examine several specific activities that use active learning strategies such as jigsaws, role-playing, and gallery walks. Several module authors will also join us and give brief overviews of highlights of their modules.

Fostering Systems Thinking in Your Students

Mar 22 2017 Systems thinking can help students analyze complex systems and it is well-suited to teaching about Earth in a societal context. Systems thinking is prevalent across the curriculum, especially with regard to sustainability issues. Lisa Gilbert, Systems Thinking module co-author, will introduce systems thinking, provide an approach to building students' systems thinking skills, and showcase a systems thinking example that can be used in any course. Karl Kreutz, Systems Thinking module co-author, will discuss systems modeling and feedback systems. In addition, he will provide an example of a feedback system using Arctic sea ice. The webinar will include 30 minutes of presentations and 25 minutes of discussion. Participants are encouraged to both ask questions of the presenters and discuss their own experiences regarding systems thinking for their discipline or context.

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How to Use »

Lisa Gilbert: Using Systems Thinking in Oceanographic Processes at Williams-Mystic

About this Course

An intermediate-level course for majors and non-majors.

17
students
Two 75-minute classes and one 3.5-hour lab per week

Williams-Mystic S16 Oceanographic Processes Syllabus Lisa Gilbert (Microsoft Word 67kB May23 16)

Lisa Gilbert setting up sample bottles during the Williams-Mystic offshore field seminar.

GEOS210/MAST11: This course examines ocean and coastal environmental science issues including carbon dioxide and the ocean's role in climate, El Niño and other ocean-atmosphere oscillations that influence our weather, coastal erosion and other hazards, coastal pollution, and fisheries. The focus is on controlling processes with regional comparisons. Blue water oceanography is conducted in the Atlantic and comparative coastal oceanography includes trips to southern New England shores, and the West and Gulf coasts of the United States as part of the Williams-Mystic program.

Class Format: lecture/laboratory, including coastal and near-shore field trips, 11 days offshore, and a laboratory or field research project

Course Goals:

1. Design and complete a semester-long research project that is both quantitative and original.
2. Use a variety of scientific tools to measure coastal and water column properties.
3. Make reasoned predictions based on scientific data.
4. Explain how feedback loops can stabilize or exacerbate change in the ocean.
5. Distinguish between gradual, oscillating, and episodic variability in the ocean.
6. Compare multiple natural and anthropogenic influences on ocean change.
7. Evaluate the U.S. Northeast, Gulf, and West coasts in terms of coastal hazards, resources, and risk resilience.
8. Apply systems thinking to make connections between marine science, history, policy, and literature, in the broad context of sustainability.

A Success Story in Building Student Engagement

A desire for interdisciplinary problem-solving skills is one of the reasons students apply to study for one semester at The Maritime Studies Program of Williams College and Mystic Seaport (Williams-Mystic) from all over the country. While students learn approaches from science, policy, history, and literature at Williams-Mystic, teaching the Systems Thinking Module was an explicit effort at teaching students systems language, diagrams, and modeling. The ability to solve complex problems using systems thinking develops over time. Half of the group completed the entire module and was very engaged in and excited by complex problems. Half of the group completed only one unit, and while they showed improved confidence with systems diagrams, the ones not previously exposed to systems thinking did not generalize beyond the examples given. My students were very engaged in using systems thinking to approach ocean change, from conceptual diagrams to modeling.

My Experience Teaching with InTeGrate Materials

The examples in the module were easily modified to fit the topics of my course. Even the examples that at first seemed unrelated, such as the MPR piece about wildfires in Minnesota (Unit 1), were an excellent opportunity for students to think about climate teleconnections with the ocean.

Relationship of InTeGrate Materials to my Course

The Maritime Studies Program of Williams College and Mystic Seaport (Williams-Mystic) is an off-campus semester focused on the sea. Students take four courses: Marine Policy, Maritime History, Literature of the Sea, and their choice of one of two science courses (Marine Ecology or Oceanographic Processes); they also take a maritime skill two afternoons a week (shipsmithing, chanteys, canvas work, small boat handling, or demonstration squad).

The Williams-Mystic semester is 17 weeks long and for many of the activities and experiences the class is all together—that is, the Oceanographic Processes and Marine Ecology students are not separated. Week 1 is spent in preparation for going to sea. Weeks 2 and 3 are spent at sea on an oceanographically-equipped tall ship, learning to sail, learning the tools of an oceanographer, and getting a sense of life at sea as context for the rest of the semester. Weeks 4, 5, and 6 are spent out and about in southern New England, learning coastal field tools and refining research questions in preparation for writing a proposal. Weeks 7 and 10 are spent on coastal field seminars to the Pacific Northwest and southern Louisiana, respectively. During the remaining weeks, students devote about 50% of their time for the course on their independent research projects. I work with them individually or in pairs to move from proposal to data collection to analysis, and students produce a written report and give a conference-style presentation.

Unit 1 was completed by the whole Williams-Mystic class, both Marine Ecology and Oceanographic Processes students (n=17) at the end of Week 9. Unit 1 was the first hour of a three-hour class on sea level rise used to help prepare students to make observations in Louisiana.

Units 2–6 were completed during the last 7 weeks of the semester, Weeks 11 through 17.

Week 9 — March 24, 2016: Unit 1

Unit 1 was 50 minutes of class. Students cited the radio piece as especially important to their learning.

I started with a pre-instruction knowledge survey and ended with the same survey. Students' confidence with systems thinking increased in the 50-minute Unit 1.

- At the start of the first unit, 15 of 17 students had either never heard of systems diagrams (n=6) or had heard of them but thought they could not elaborate (n=9).
- At the end of the Unit 1, 14 of 17 students believed they could explain a systems diagram if given one and 9 of 17 students believed they could create a systems diagram and then explain it.

Week 11 — April 5, 2016: Unit 2

Unit 2, Part 2 was about 45 minutes of a class about coastal eutrophication. I asked students to assess key impacts of coastal eutrophication using Bricker et al. (2003) classification and Bricker et al. (1999) data; the class was divided into Pacific, Gulf, and East coast groups. Which estuary will be most vulnerable to eutrophication in the face of changing climate? Students then did a gallery walk activity for eutrophication diagrams. We then discussed which estuary would be most vulnerable to climate change. And, did the system diagrams gallery walk change your thinking?

Week 12 — April 14, 2016: Unit 3 & 4

We had significant Internet issues during this period, so many students had not done the pre-class work. Luckily, I had brought copies of the ISEE player and models on thumb drives for students to download during class. We did Units 3 and 4 during class; students worked in pairs. We started by labeling a system diagram activity: adding measurable quantities to the Water Cycle. Then, I did preview of STELLA/ISEE Player.

Units 3 and 4 took about 45 minutes in class, combined. The Bathtub model 3 activity worksheet took students about 20 minutes including reflection and discussion. Between Units 3 and 4, we had a 7-minute discussion about which conceptual model best represents Earth's climate system, a think-pair-share (material not from this module). Then, in about 15 minutes, students completed Bathtub model 4 worksheets and reflection.

Week 13 — April 19, 2016: Unit 4 & 5

I pre-empted the unit today with some information about the satellite sensors. Unit 4 homework as a 15 minute in-class activity. The, we discussed the seasonality of sea ice for 12 minutes, looking at summer minimum extent data, feedbacks with hurricanes, applications to the Northwest passage, and international marine policy. One student asked "How does the decrease in sea ice affect polar bears?" and we discussed the Arctic food web and the polar bear's feeding strategies. Then we moved on to a larger discussion of heat. I prompted the class to vote on the question, "Which holds more heat: the ocean or the atmosphere?" (4 said ocean; 2 said atmosphere; one student refused to vote). We discussed the heat capacity of water, trends in atmospheric water vapor and implications, and cloud feedbacks. Finally, for 13 minutes in class, students completed the heat balance exercise, which I modified slightly from Unit 5, Part 2.

Week 16 — May 12, 2016: Unit 6

I've been using the Unit 6 activity as my last class period for over a decade, and students have very positive responses to it. Because my class is small, I give only a brief introduction and then let them figure it out as I walk around. With a larger class, I imagine I would do a full demonstration of the three parts of the activity (i. *Find* a partner, ii. *Discuss* answers to your review question and your partner's review question, iii. *Write* some of the possible connections between the two topics, iv. *Move* on.) Students moved around the room, pairing up 5–6 times in 40 minutes, and I acted as a member of the class since I have an odd number of students. During the 15 minute follow-up discussion, I drew the complex connections on the board and made a big mess, but it drove home the point that everything is related.

Week 17 — May 18, 2016: Summative Assessment

The summative assessment was 25% of my final exam.

Assessments

I used knowledge surveys, polling, worksheets, and exam questions to assess student learning. Students were especially receptive to the knowledge surveys which had them both focus on the learning goals at the start of class and self-assess their progress. I do not normally use worksheets in class, so those were the most incongruous, but students responded well to the scaffolding for modeling that the worksheets provided. Several students came to me and said that the summative assessment and another question on my exam (asking them to design an interdisciplinary capstone assignment) were the two best questions they had ever been asked on an exam and the most fun.

Outcomes

The module is well-aligned with my course goals #3, 4, 5, 6 and 8.

Course Goals:

1. Design and complete a semester-long research project that is both quantitative

and original.
2. Use a variety of scientific tools to measure coastal and water column properties.
3. Make reasoned predictions based on scientific data.
4. Explain how feedback loops can stabilize or exacerbate change in the ocean.
5. Distinguish between gradual, oscillating, and episodic variability in the ocean.
6. Compare multiple natural and anthropogenic influences on ocean change.
7. Evaluate the U.S. Northeast, Gulf, and West coasts in terms of coastal hazards, resources, and risk resilience.
8. Apply systems thinking to make connections between marine science, history, policy, and literature, in the broad context of sustainability.

My students stated that they believed that they had met all of the goals at the end of the semester.

The module exceeded my expectations and goals in one important way: I came to value modeling as an accessible tool for students. Previously, I had taught individual students MATLAB to make models, but only those who had the inclination and experience to do so. Using the ISEE player opened my eyes to new possibilities in class and for student research projects.

Considering using these materials with your students?
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Deborah Gross: Using Systems Thinking in Climate Science at Carleton College

About this Course

An introductory course for students who have had one introductory science or math course previously. This course counts as an elective for the environmental studies major.

18
students
Two 70-minute and one 60-minute class sessions per week for 9.5 weeks. ENTS 287 Fall 2015 Syllabus (Acrobat (PDF) 50kB Jun21 16)

ENTS 287: Climate Science
In this course, we will explore the state of the science of the modern global climate. The course will include a discussion of the impact of greenhouse gases and aerosol particles on the global climate system, and attention will be paid to understanding global cycles as well as global climate models. In order to understand the underlying science, geoengineering schemes to "fix" the global climate system will be investigated. Throughout the course, our emphasis will be on a quantitative, scientifically rigorous understanding of the complex climate system. Prerequisites: One introductory course in Biology 125 or 126, Chemistry 123 or 128, any 100-level Geology, or Physics (two five-week courses or one ten-week course from 131-165) and Math 111 or 215, or consent of the instructor 6 credit; Does not fulfill a curricular exploration requirement, Quantitative Reasoning Encounter.
By the end of this course, I hope students will be able to:

- Describe complex systems using appropriate terminology.
- Diagram complex systems graphically.
- Qualitatively and quantitatively describe major scientific principles which contribute to Earth's climate system.
- Explain the major arguments made in support of the idea of human-caused climate change and be able to critique the scientific claims.
- Explain the major arguments made against the idea of human-caused climate change and be able to critique the scientific claims.
- Describe the differences between long and short-lived climate forcers, and assess proposals to address human-caused climate change through technology that impacts emissions of both.
- Gain experience with obtaining and interpreting results from a General

Circulation Model (GCM, a climate model).
- Develop hypotheses for future climate responses to specific human behaviors and test those hypotheses using a GCM.
- Assess the roles of uncertainty and risk in our assessment of climate change.
- Use your knowledge to read scientific articles on topics related to climate.
- Provide a critique of policy recommendations related to global climate issues, based on the scientific issues guiding them.
- Apply a scientific understanding of the climate system in other situations, whether your future research, other courses you take, your assessment of policy, or your own personal choices.

A Success Story in Building Student Engagement

My Climate Science course is an introductory-level course, although it requires students to have one college-level math or science course as a pre-requisite. It is typically taught with a mix of lecture, discussion, and student-directed projects, so the activities in this module fit right in!

When I taught this course previously, my students and I had discussed the complexity of Earth's climate system throughout the course, but we had not taken the time to specifically develop the tools for describing complex systems through diagrams, as this module helped us do. The students were able to transfer these skills to all aspects of their course, and hopefully into other areas, as well.
In the offering of the course where I used this module, my students were always drawing systems diagrams and were specifically using the methods, vocabulary, and habits of mind that they developed through the material in the module, in all aspects of the course.

My Experience Teaching with InTeGrateMaterials

I used the module essentially as-is. The only way I changed things for my course was that I did not use the PowerPoint presentations in Units 1 and 2, but instead led discussions with the students, where I (or they) drew on the board to illustrate points.

Relationship of InTeGrate Materials to my Course

My course is 9.5 weeks long (28 class meetings), and I started the module right at the beginning. I did Units 1 and 2 on the second and third days of class. Units 3 and 4 were done about 1 month later, one week apart. Units 3 and 4 were done around the same time that we were learning to use EdGCM, a climate model, and working with simulation results from it. I introduced the bathtub models as a way to actually work with the individual calculations that are within a climate model, one at a time. Unit 5 was done just after Unit 4, right after we had a deep foray into the Carbon Cycle, because of an article that we had read and discussed in class. We developed our own (partial) model of the Carbon Cycle in that conversation. Thus, I chose to use the Carbon Cycle example for this unit, so that we looked at a complete version. Unit 6 was done on the second-to-last day of class.

Unit 1: I used this unit to launch the content of the Climate Science class. It got us situated in how to think and talk about complex systems, which we drew upon throughout the rest of the course. The radio piece about fires and their impact on ice albedo was something we came back to multiple times in the course, in subsequent discussions of Earth's radiative balance, aerosols, short-lived climate forcers, and other topics.

Unit 2: We completed Unit 2 immediately after Unit 1. We started class with a discussion about the functional form of response of variables versus time, to introduce the quantitative nature of the system diagrams, and about the fact that the components of the systems diagram that are buried or not included depend on the perspective of the person drawing it, so that the perspective of the creator of the diagram matters. This introduced a more critical approach to the problem. The students drew diagrams, did a gallery walk, and revised their diagrams. The homework assignment was highly successful, with students coming up with various interesting local systems. The system described by the largest number of students was the campus post office. After Unit 2, nearly every student automatically drew a systems diagram whenever we were discussing a complex system.

Unit 3: We waited too long to get to Unit 3, for a variety of reasons, but we used it as a quantitative introduction to modeling just after embarking on a class project to use EdGCM (more info) , a Global Circulation Model that allowed students to engage with a research-grade climate model. We started by looking for an inflow-reservoir-outflow component in the system diagram that they drew in Unit 2 (after reforming the groups and handing back a printout of their submitted Unit 2 model). When asked to think about equilibrium, and to estimate values for the reservoirs and fluxes, they were comfortable with the former and struggled with the latter. They then used the STELLA models in the ISEE Viewer, which students downloaded onto their own laptops at the beginning of class. This gave the students a chance to see how adjustments to reservoirs and fluxes could dramatically affect system behavior. They were able to extrapolate this experience to the individual calculations that occur in the GCM, which was a nice way to give them a feel for what was happening "behind the scenes" in it. They were interested in exploring the equations behind the exercises that were provided, and found the illustrations to be helpful. We needed to do another activity at the end of the class period, meaning we had only 35 minutes for the unit, so students finished Experiment 2 and did the homework on their own after class.

Unit 4: Unit 4 was done a week after Unit 3, based on the specifics of our course schedule. Students were ready to go, and we discussed the real-world examples quickly, with a longer discussion about the fact that reinforcing feedbacks can be "friend" or "enemy" — that it is context-specific. The students made good progress through the investigation of feedbacks, completing most of the second experiment before we had to stop to move on to another scheduled activity. They completed the work and the homework after class.

Unit 5: We did a project related to The Carbon Cycle right before working on Unit 5, so we used this as the example in Unit 5. As a result, we were well primed, and dove right into looking at this system and thinking about what could be represented quantitatively. The exercise went well once I gave them a specific outline to follow: step 1: Think about numbers: reservoirs and fluxes. Sketch graphs on half-sheets of paper. Must include 1 flux and 1–2 reservoirs, where at least one must change with time; step 2: Attach collage, including carbon cycle, to whiteboard; step 3: Gallery walk, looking at each others', and then adjusting their own if needed. They had good discussions, and they found it interesting to use content knowledge to flesh out the connections in the diagram. The discussion about how to learn what they needed to learn was engaged, and they had good ideas. The homework went well, and their responses showed a strong understanding of the need to bring in resources from a variety of sources to understand something as complex as The Carbon Cycle.

Unit 6: We did this activity on the second-to-last day of class, and used it as described: to assemble the types of concepts that we had discussed throughout the term. Students had already done the summative assessment for the module before this class; it was done as homework and was due this class period. For this exercise, I created a list of questions, based on the number of students in the class, and got them set up in initial pairs. I introduced the exercise to them as a "Climate Science Speed Dating" game, and they got the concept well, but were not fast enough in the first round. In subsequent rounds of discussion, I ended up choreographing their interactions more closely, calling time when they needed to switch which question they were discussing at 1.5 and 3 minutes, and telling them to switch to discussing how to link their topics. We went through three rounds of questions. This activity was a fun way to finish the term. The discussion afterward was a bit more challenging, as there were not specific topics that stood out as especially problematic to link.

Assessments

I used all of the assessments that are included in the module. The most engaging to the students was the photo collage in Unit 2 — they took that assignment to heart and spent a lot of time on it, making really wonderful diagrams. They solidified their understanding through each of the exercises, and I think they all went well.

Outcomes

I anticipated that the students in my class would have a more specific and more disciplined way of discussing the "system" part of the climate system — the topic of the whole course. This was in fact the case, as after Unit 2, drawing system diagrams, and explaining course material using appropriate systems language, was a natural part of their discourse. The ability to work with the STELLA models enhanced our introduction to a GCM, shedding light on the inner-workings of such a model, although I believe that all of my students would have been happier working in the full version of STELLA, where they would have been able to adjust the model, rather than just the inputs. However, given the software availability, having the free viewer was fantastic. Overall, my students were more sophisticated in their formal engagement of systems throughout the course.

Classroom Context

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Karl Kreutz: Using Systems Thinking in Global Environmental Change at University of Maine

About this Course

Lower-division course for Earth and Climate Science majors; typically I have a range of freshman to seniors, and a range of natural and social science majors.

20
students

Two 75-minute lecture sessions and one 3-hour lab per week

ERS201 Syllabus (Acrobat (PDF) 215kB Jul23 18)

Global Environmental Change (ERS 201) examines the physical and chemical interactions among the primary systems operating at Earth's surface (atmosphere, hydrosphere, cryosphere, biosphere, lithosphere) on various timescales throughout geologic history. We will consider internal and external forces that have shaped environmental evolution, including the role of humans in recent geochemical and climatic change. During lecture and laboratory sessions, our goals are to develop critical thinking and writing skills and a scientific approach to the complex array of feedbacks operating at Earth's surface, as well as an appreciation for how past environmental change informs current societal issues. Course may include field trips during class hours.
Course Goals: In ERS201: Global Environmental Change, students will:

- Use a systems approach to study the interaction of surface processes linking the atmosphere, hydrosphere, biosphere, lithosphere, and anthrosphere
- Explore Earth system proxy records to appreciate the dynamic range and rates of climate and environmental change
- Investigate the influence of humans on surface processes using geochemical tools
- Use systems models to best explain available geological evidence
- Couple past and present Earth system data with societal trends to evaluate future climate scenarios
- Practice experimental design, data acquisition, uncertainty analysis, data interpretation, and communication in the field, laboratory, and classroom
- Develop evidence-based scientific argumentation skill using data from multiple sources (direct and remote observation, and models)

A Success Story in Building Student Engagement

My course focuses on the reservoir of atmospheric carbon dioxide — what controls it, how it has changed in the geologic past, how it is changing now and the role that humans have played in its evolution, the effects on Earth's energy balance, and potential future climate and environmental implications. Because these processes play out on a range of time and space scales, direct experimentation is difficult in an undergraduate setting. Systems thinking provides an ideal platform for understanding the flow of carbon between reservoirs, and for gaining an appreciation of how important the intersection of Earth science and society is with respect to carbon, climate, and energy. Implementing this module made a dramatic difference in the class, improving student learning on everything from global models of the carbon cycle to the formation and flow of methane in our local peat bog.

Using this module assured me that students left class with a fundamental set of systems thinking skills, something that is critical for addressing any of the grand Earth science challenges facing us as a society.

My Experience Teaching with InTeGrateMaterials

I used the module essentially as is. I modified the materials to be specific to my course where necessary, which most often meant only very minor changes. I did adapt one unit (five) to be specific for my class as necessary, focusing on the long-term carbon cycle. I came to appreciate the flexibility we designed into the module, so that it can easily be adapted to any instructor's specific needs.

Relationship of InTeGrate Materials to my Course

My course runs for a 14-week semester. I did Units 1–4 during the second and third week of the course, after introducing students to the global carbon cycle and atmospheric CO2 variability on different timescales. Units 5 and 6 were done later in the course, to introduce new aspects of the long-term carbon cycle and then to synthesize overall carbon cycle knowledge from a systems perspective.

- **Unit 1: Introduction to Systems Thinking:** a great beginning, after having already shown students how a particular reservoir (atmospheric CO2) varies on different timescales, without first having assigned systems terminology to anything. Having students begin with a familiar system (a bathtub), and build complexity through the unit, was fantastic.
- **Unit 2: Picturing a System:** This was a great introduction to systems diagramming, using the global carbon cycle. Students were able to diagram, gallery walk, and importantly begin to identify where quantitative information could/should be used. I integrated the homework into a field trip to a local bog.
- **Unit 3: Modeling a System:** This unit provided our course with a transition to using quantitative information to evaluate a system. Using a simple bathtub model provided continuity between our systems diagramming and systems

modeling efforts, and could easily be related to process in the carbon cycle.

- **Unit 4: Feedbacks in a System:** We continued our use of the bathtub systems model, and incorporated both positive and negative feedbacks. The systems model was particularly useful for demonstrating both balancing and reinforcing (runaway) behavior, and tipping point behavior. Relating it to a real world example (Arctic sea ice) was instructive for students.
- **Unit 5:** I used this unit to introduce processes in the long-term carbon cycle. Using a combination of systems diagramming, and identifying quantitative information, was easier here because of the background students had from Units 1–4.

Assessments

I used all of the in-class assessments, and found that students responded well to them. Each is designed to provide an active learning experience, and indeed they each fostered an active dialogue among students and between students and instructors. I used about half of the homework assessments, relying instead on other lab assignments and problem sets that were aligned with the course objectives. I also used a somewhat modified summative assessment (Acrobat (PDF) 110kB Jul23 18), which focused on the scientific argumentation skills that we developed throughout the course. In general, I found that students were fully engaged in the Systems Thinking assessment materials.

Outcomes

My original goal was for students to develop a solid grasp of two fundamental systems thinking concepts: equilibrium and feedbacks. In the past, these concepts have proven challenging to isolate and teach effectively, especially when trying to convey the broader relevance in science and society. I think the combination of systems vocabulary, diagramming, and modeling that are used in the module were quite successful for teaching those concepts. When I gave the course summative assessment, I was pleased with the level of discussion and understanding students were able to achieve with respect to carbon cycle dynamics, climate, and human impacts.

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Join the community of educators interested in the Systems Thinking module. Whether you're just starting to explore the materials or have already adapted them for use with your students this is the place to ask questions and share your experience.

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We invite you to create a new discussion thread below and:

- **Ask a question**. This group includes teachers who have classroom experience using these materials.
- **Share your experience using the materials**. What worked well? What didn't? How did you adjust the materials to work with your students?
- **Share your favorite enhancements or supporting resources**.

InTeGrate: Systems Thinking Discussions

id	Thread	Posts	Most Recent Posting
11501	New version of STELLA player Lisa Gilbert Jan, 2017	1	The Systems Thinking has been updated by the ... Lisa Gilbert Jan, 2017
12479	Visualizing Systems Lisa Gilbert Dec, 2017	3	Thank you for your feedback. I do think there is ... Lisa Gilbert Dec, 2017
13658	How to Draw a Systems Diagram slides? Tim Burnett Oct, 2018	1	I am running a course on Sustainability and ... Tim Burnett Oct, 2018
13744	Effectiveness of the Systems Thinking Module Lisa Gilbert Nov, 2018	1	A new paper describing the Systems Thinking ... Lisa Gilbert Nov, 2018