MODULE 2 (EARTH SCIENCE) INTRODUCTION

Module Name: Water as a Shared Resource

Content of this Introduction:
1. Overview of the Module
2. Prerequisite knowledge and assumptions encompassed by the Module
3. Standards covered by the Module
4. Materials needed for the Module
5. Pacing Guides for 5 Lessons, including Learning Objectives and Assessment Questions

1. Overview of the Module

This Earth Science module considers how humans are impacting the environment and how resources are being used and managed (or not managed) for the future. In particular, the module explores ground water as a shared resource and factors that affect how a resource is shared among stakeholders. Students investigate the movement of water through the hydrological cycle. The base model for this unit simulates the part of the hydrological cycle in which water falls as rain, seeps into an aquifer, and is pumped out by a single pump. Students walk through each part of the model, run experiments to better understand the model, and then modify the base model to add additional pumps and/or add variable rates for rainfall, pumping, and infiltration (soil types).

2. Prerequisite knowledge and assumptions encompassed by the Module

This Earth Science module offers some disciplinary core concepts through direct instruction and activities but assumes the students already possess a certain level of knowledge in key areas. Concepts such as the hydrological cycle, watersheds, surface water, ground water, precipitation, percolation, aquifers, porosity, and infiltration are reviewed, but in order to achieve deeper learning it is advisable that the students will have covered these concepts beforehand. A recommended video resource that provides coverage of these concepts is available at: https://www.youtube.com/watch?v=R8NQUQDZ3N0. An alternate video is available at: https://www.youtube.com/watch?v=al-do-HGuIk.

It is necessary to have completed Module 1 prior to commencing this module, in order to have the necessary skills to complete the activities in this module.

3. Standards covered by the Module

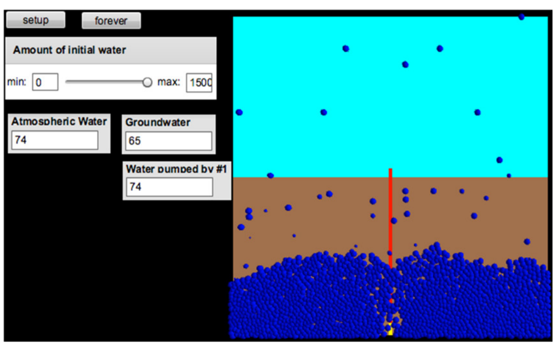
Please see the Standards Document for a detailed description of Standards covered by this Module, Lesson by Lesson.

4. Materials needed for this Module

You will need the following materials to teach this module:
- Computer and projector
- Water Resources background videos [for reference]
  “Water and You” https://www.youtube.com/watch?v=R8NQUQDZ3N0.

"The Water Cycle" https://www.youtube.com/watch?v=al-do-HGuIk.

- Link to the Water for Life – Jay-Z video (no longer on MTV)
- Large bucket of water for lesson 1 activity #2 (on day 1)
- 10 to 12 plastic cups for lesson 1 activity #2 (on day 1)
- Water source for lesson 1 activity (on day 1)
- Water pump base StarLogo Nova models
- Guided Introduction to StarLogo Nova document [for reference]
- CS Concepts guide document [for reference & student handout]
- StarLogo Nova Blocks Reference Guide [for reference & student handout]
- StarLogo Nova Blocks Reference Guide Module 2 [for reference & student handout]
- Scientific Practices with Computer Modeling & Simulation document [student handout]
- Experimental Design Form document [student handout]
- Model Observation Form [student handout]
- Project Design Form [student handout]
- Model Design Form [student handout]
- Lesson plans for 5 lessons
- Slide presentation with instructions
- New commands and concepts sheets for each lesson [student handout]



5. **Pacing Guides for 5 Lessons, including Learning Objectives and Assessment Questions.** (See following pages.)

DAY 1: Introduction to Water as a Shared Resource

Pacing Guide

Getting Started	Introduce the Water as a Shared Resource module and sharing resources / cooperation as a complex system phenomenon.	5 mins
Activity 1	Watch & discuss Diary of Jay-Z in Africa: Water for Life.	15 mins
Activity 2	Shared Water hands-on activity; experience the sharing of water resources from the perspective of various stakeholders.	25 mins
Wrap-Up	How can computer modeling help us understand resource limitations and sharing?	5 mins

Learning Objectives: Students will…

Complex Adaptive Systems	Be able to describe how a community of water users can be studied as a complex system phenomenon: there are many agents interacting following simple rules, there is no leader, there are emergent patterns and the system may be unpredictable [**LO2**].
Disciplinary Core Ideas	Learn of limitations of and threats to fresh water supplies [**LO1**]. Consider the importance of water for our survival [**LO3**].
Modeling and Simulation	Learn that models can be used to investigate water sharing scenarios and or policies. [**LO4**].

Assessments of Understanding:

Complex Adaptive Systems	List two characteristics of water resources that show it is a complex system [**LO2**].
Disciplinary Core Ideas	List two threats to fresh water supplies [**LO1**]. List three ways humans are dependent on water for survival [**LO3**].
Modeling and Simulation	Why are modeling and simulation useful in understanding water resource management? [**LO4**]

DAY 2: Math Basics for Modeling and the Water Pumping Base Model

Pacing Guide

Getting Started	Review of the previous day's lesson and concepts. Connection to today's lesson.	5 mins
Activity 1	Review math basics for modeling: coordinate space, relative vs. absolute position, agent heading, and angles of rotation.	20 mins
Activity 2	Under the Hood: Inspecting the Water Pumping model. Find commands that are familiar and ones that are new. Decode model by procedures. Run the model multiple times.	20 mins
Wrap-Up	Is anything unexpected happening in the model?	5 mins

Learning Objectives: Students will…

Complex Adaptive Systems	Make observations of water being pumped out of the ground in the model. Identify an emergent pattern in the water pump model [**LO5**].
Disciplinary Core Ideas	Learn that water continually cycles among land, ocean, and atmosphere [**LO6**].
Modeling and Simulation	Identify abstractions made and limitations of the model [**LO7**]. Use the Water Pumping base model to conduct a repeated experiment and make observations (drawing simple correlations) [**LO8**].
Computer Science	Decode a model. [**LO9**] Trace a program's execution [**LO10**].

Assessments of Understanding:

Complex Adaptive Systems	What is an emergent pattern being formed when we run the model? [**LO5**]
Disciplinary Core Ideas	Identify which part(s) of the water cycle is represented in the Water Pumping model? [**LO6**]
Modeling and Simulation	What are some of the abstractions or simplifications made in the model? [**LO7**] What were some of the observations you made as you ran the model? [**LO8**]
Computer Science	Name three blocks of code you recognized and what each one does [**LO9**]. List the steps the program executes in order in the forever loop [**LO10**].

DAY 3: Adding More Water Pumps and Running Experiments

Pacing Guide

Getting Started	Review of the previous day's lesson and concepts and connection to today's lesson.	5 mins
Activity 1	Add another pump to the Water Pumping base model and add monitors and graphs that collect data on the amount of water pumped by each pump.	20 mins
Activity 2	Design and run an experiment to see the effect of the modification. What is the impact of multiple users? What factors determine which user gets more water?	20 mins
Wrap-Up	What does the computer model enable us to do that would be difficult to do in the real world? How could a model like this one be used to manage water resources?	5 mins

Learning Objectives: Students will…

Disciplinary Core Ideas	Learn that typically as human populations and consumption of natural resources increase, so do the negative impacts on Earth [**LO11**].
Modeling and Simulation	Ask a question that can be answered using the model as an experimental test bed [**LO12**]. Design and conduct an experiment [**LO13**]. Collect and analyze data to look for patterns [**LO14**].
Computer Science	Modify a simple computer model and display output data using widgets [**LO15**]. Practice Pair Programming and Iterative design, implement, and test cycle [**LO16**].

Assessments of Understanding:

Disciplinary Core Ideas	Describe potential negative impacts of adding additional water wells in a community with limited water resources [**LO11**].
Modeling and Simulation	See student Model Design Form and Experimental Design Form [**LO12, LO13,** and **LO14**].
Computer Science	Describe a procedure you added to the model [**LO15**]. In your own words, describe how you tested and, if necessary, refined your procedure [**LO16**].

DAY 4: Customizing Your Water Pumping Model

Pacing Guide

Getting Started	Review of the previous day's lesson and concepts and connection to today's lesson.	5 mins
Activity 1	Introduce key elements of the computational science process. Discuss other factors that impact water availability. Discuss local or regional issues affecting water supply or quality. Then define your computational science project.	20 mins
Activity 2	Design and develop your customized model in teams. Ideas for topics to investigate include variable rainfall, soil types, pollution, and/or regulations that impact water use.	20 mins
Wrap-Up	What research is necessary to ground your model in reality? How will you check to see if your model is realistic?	5 mins

Learning Objectives: Students will…

Disciplinary Core Ideas	Learn that resources are distributed unevenly around the planet as a result of past geologic processes [**LO17**]. Humans depend on water resources and many of these resources are not renewable or replaceable over human lifetimes [**LO18**].
Modeling and Simulation	Use the key stages of computational science and project design form to develop a question, create a model, and design an experiment [**LO19**].
Computer Science	Implement problem solutions using looping behavior, conditional statements, logic, expressions, variables and functions [**LO20**].

Assessments of Understanding:

Disciplinary Core Ideas	Give three examples of how local conditions affect water supply or quality [**LO17**]. Describe why some water is not renewable or replaceable; where does the water go? **[LO18]**
Modeling and Simulation	See student Project Design Form. (Did student choose a question appropriate for answering with the model? Could student explain why it was chosen? Did student describe the aspects of the real world to be included in the model and why they were selected? etc.) [**LO19**]
Computer Science	Describe procedures in the model that you built. Choose one and describe how it works in detail [**LO20**].

DAY 5: Experiment with Your New Water Pumping Model

Pacing Guide

Getting Started	Review of previous day's lesson and concepts and connection to today's lesson.	5 mins
Activity 1	Complete and debug code.	15 mins
Activity 2	Run experiments, analyze results and discuss conclusions. Relate the results back to the bigger issue of shared resources and ground water. Prepare your model and results for presentation.	25 mins
Wrap-Up	How would you know if your model reflects reality? What research is necessary to check if your model reflects the real-world?	10 mins

Learning Objectives: Students will…

Complex Adaptive Systems	Revisit complex systems concepts and learn how they relate to understanding resource management [**LO21**].
Disciplinary Core Ideas	Gain a deeper understanding of impacts on ground water resources through experience creating and experimenting with a water pump model [**LO22**].
Modeling and Simulation	Use customized model as an experimental test bed to run experiments [**LO23**]. Learn that multiple runs of the experiment are needed at each variable setting due to inherent randomness in the model [**LO24**].
Computer Science	Use iterative refinement and apply debugging techniques to isolate and fix errors in code [**LO25**].

Assessments of Understanding:

Complex Adaptive Systems	Describe four characteristics of a complex system and how they relate to a resource management situation [**LO21**].
Disciplinary Core Ideas	What local or regional issue impacting water resources was included in your model? What are some of the potential impacts of that factor or condition? [**LO22**].
Modeling and Simulation	See student Experimental Design Form [**LO23, LO24**].
Computer Science	Give an example of how you were able to find and fix an error you had in your code [**LO25**].

2

Lesson 1

Introduction to Water as a Shared Resource

50 minutes (1 day)

Lesson Overview (New Learning – guided by teacher)

In this lesson students will engage in discussion about water resources and group decision-making, stimulated by a video and a participatory simulation that serve to highlight group decision-making dynamics. The video will serve to get students thinking about water resources and the difficulties some people their age face in obtaining safe drinking water. The two activities will provide background on how communities make decisions, especially when dealing with a shared resource like water.

Teaching Summary

Getting Started – 5 minutes

1. Water as a Shared Resource Overview

Activity #1: Water for Life – 15 minutes

2. Watch and discuss "Water for Life: Diary of Jay-Z in Africa" video
3. Sources of fresh water: ground water vs. surface water

Activity #2: Water Sharing – 25 minutes

4. Participatory Simulation: "Some for All or All for One"
5. Debrief the participatory simulation

Wrap-Up – 5 minutes

6. How can computer modeling help us understand resource management?

Lesson Objectives

The student will:

- ✓ Learn of limitations of and threats to fresh water supplies [LO1]
- ✓ Be able to describe how a community of water users can be studied as a complex system [LO2]
- ✓ Consider the importance of water for our survival [LO3]
- ✓ Learn that models can be used to investigate water sharing scenarios and or policies [LO4]

Teaching Guide

Materials, Resources and Preparation

For the Students

- Computers
- Paper cups

For the Teacher

- Computer and projector
- Water Resources background document
- Link to the “Water for Life: Diary of Jay-Z in Africa” video
- Water jug
- White board or large flip chart and markers

Getting Started - 5 min

1. Water as a Shared Resource overview

Start with a quick overview of relevant earth science concepts using direct instruction. (It is expected that the students have learned these concepts prior to encountering them in this module.)

- [ESS3.A: Natural Resources] Living things need water, air, and resources from the land, and they live in places that have the things they need. Humans use natural resources for everything they do.
- [ESS3.C: Human Impacts on Earth Systems] Things that people do to live comfortably can affect the world around them. But they can make choices that reduce their impacts on the land, water, air, and other living things. Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.
- [MS-ESS2.C: The Roles of Water in Earth’s Surface Processes] Water is found in the ocean, rivers, lakes, and ponds. Water exists as solid ice and in liquid form. Nearly all of Earth’s available water is in the ocean. Most fresh water is in glaciers or underground; only a tiny fraction is in streams, lakes, wetlands, and the atmosphere. Water’s movements—both on the land and underground—cause weathering and erosion, which change the land’s surface features and form underground formations.
- [MS-ESS2.C: The Roles of Water in Earth's Surface Processes] Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. Global movements of water and its changes in form are propelled by sunlight and gravity.
- [MS-ESS3.A: Natural Resources] Humans depend on Earth’s land, ocean, atmosphere,

and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.

Activity #1: Water for Life - 15 min

In this activity, students will watch a compelling video then review the sources of fresh water and the difference between ground water and surface water.

2. **Watch and discuss "Water for Life: Diary of Jay-Z in Africa" video**
    - Link to the "Water for Life: Jay-Z in Africa" video (no longer linked from MTV)
    - Watch from 00:00 to 07:37 on the video.
    - What was the most surprising thing you learned in this video?

3. **Discuss the sources of fresh water and the difference between ground water and surface water**
    - Most fresh water is in glaciers or underground; only a tiny fraction is in streams, lakes, wetlands, and the atmosphere.
    - Which sources are ground water [aquifers, subglacial lakes] and which are surface water [streams, lakes, wetlands]?
    - Even though the amount of water locked up in glaciers and ice caps is a small percentage of all water on (and in) the Earth, it represents a large percentage of the world's total freshwater. The majority of freshwater on Earth, about 68.7 percent, is held in ice caps and glaciers. (Source: water.usgs.gov/edu/watercycleice.html)

Teaching Tip *It is important to be sensitive to the fact that students in some regions of the country also live without readily-available sources of fresh water.*

Activity #2: Water Sharing - 25 min

4. **Participatory Simulation: "Some for All or All for One"**
   This activity is designed to highlight some of the interesting dynamics that come about when a group of individuals has to make decisions regarding a shared resource. In this "participatory simulation" students will act as stakeholders in a water-sharing scenario. When considering a shared resource like a water well, it is important to understand that each member in a community that uses this well has an impact on every other well user. An individual has the ability to choose what amount of the resource they will take based on some simple rules.

    - Before running the participatory simulation, fill the water bucket with the equivalent of 6 drinking cups of water. (Use the plastic cups that will be distributed to the stakeholders.)
    - Select 10 to 12 students to play the roles of stakeholders in a community. The remaining students are observers who should quietly observe the game in progress.
    - Have the stakeholders form a circle then face out from the center.
    - Give each stakeholder an empty cup.
    - Tell the stakeholders that they will have the opportunity to take the water they need.
    - Tell the stakeholders that whatever is left in the bucket at the end of the round, the teacher will double and redistribute to everyone equally.

- Note that since the stakeholders are facing away from the center of the circle; they cannot see each other's action.
- Play three rounds as follows.
  Round 1: (Do group discussion prior to playing the round.)
  - Explain the rules then play one round as specified above. Each stakeholder has the opportunity to take the water he or she needs, up to a full cup's worth.
  - Remember that players are facing out and shouldn't see what the others stakeholders are taking.
  - Example scenario - there are 10 stakeholders; you start with the equivalent of 6 cups of water. Each stakeholder takes the equivalent of ½ a cup. At the end of round 1, there are now 5 cups distributed among stakeholders, plus 1 cup remaining in the bucket. The teacher now doubles that to 2 cups. Each player now gets an additional 2/10 of a cup. Note that if some stakeholders take full cups worth of water, others will be left with none!
  - When all stakeholders have had a turn, have the stakeholders turn so that they are facing into the circle and compare what choices the other stakeholders made. When some stakeholders see what has happened, they might think it 'isn't fair.'
  - Remind the stakeholders that everyone made their choices individually.
  - Allow students to have a short discussion before the next round.
  - Teacher note: If all 10 players decided to take 0 cups of water, then the amount of water would be doubled to 12 cups and everyone would have more than enough to fill their cups at the end of the round. Students should not be told this but will likely figure it out on their own.

  Round 2: (Do group discussion prior to water distribution.)
  - Reset the game to the original configuration with 6 cups of water in the bucket and none in the stakeholders' cups.
  - In this round, stakeholders are allowed to have a group discussion before the water gets distributed. The group can discuss the strategies beforehand but then they must go back to facing out so they cannot see what the other stakeholders actually do.
  - Follow the same rules – the limit is 1 cup for each player, then the remaining amount gets doubled after the round and redistributed.
  - Again allow time to have a short discussion of what happened before the next round.

  Round 3: 'The Punishment' round
  - This time, do not reset the game to the original configuration!
  - In this round, each stakeholder can 'pay' the teacher 1/3 of a cup of water to take away 1 cup of water from someone else in the group.

5. Debrief the Participatory Simulation

Making decisions as an individual or as a group have can often lead to unexpected results. If you were to study the 'average' decision that individuals make, it will not always be a good predictor of what the group as a whole will decide. Individuals may act differently when they are cooperating. In small groups, humans will often cooperate because they are related or friends with the others in the groups. Cooperation and sharing resources was necessary for our human ancestors' early survival, yet cooperation still exists today. There aren't many that are 'free loaders.' People in these groups tend to help out and eventually get rewarded by receiving help from others. There are many examples of where cooperation is seen in humans - a group of hunters going after a large prey, cooperating on the playing field to win a game, community gardens and farms, volunteering to help pass out papers in the classroom, etc. However, even if cooperation is still very common in humans, it doesn't mean that everyone in a group will cooperate with a group decision. In this case, an individual could 'defect' from the cooperation yet still benefit from the resources that are in the community. In a group of cooperative people, it is often beneficial for a person to act in a selfish way.

Debrief the participatory simulation:

- Ask the stakeholders: How did you decide how much water to take? Did you change your 'strategy' after the first round? Did you consider the options for how much water to take from an individual perspective or from a group perspective?
- Most likely there are a few that are 'defectors' and act in a more selfish way. Ask "Do you think it is typical for a group of people that share a resource to have a few that act in a selfish way?"
- Ask observing (non-stakeholder) students "Can you think of any real-world situations that are similar to this game?"
- If an individual acts out of self-interest but the action ultimately proves to be self-defeating, how might they act in the future?
- Ask "What do you think would happen if there was no punishment round?"
- Relate to students that scientists study the "evolution of cooperation" using computer models and simulations of simple scenarios like the one they just played.
- Resources and further reading:
  http://www.sciencedaily.com/releases/2010/05/100501013529.htm
  http://www.beinghuman.org/article/evolutionary-benefits-cooperation

Wrap-Up - 5 min

6. **How can computer modeling help us understand resource management?**
   - If we were to model the game we just played, what would the agents represent? What rules would the agents follow? What kinds of questions could we try to answer using the model?
   - What are other resources that we need to manage in our community?

Assessment Questions

- List two threats to fresh water supplies [LO1].
- List two characteristics of water resources that show it is a complex system [LO2].
- List three ways humans are dependent on water for survival [LO3].
- Describe how modeling and simulation can be used in water resource management? [LO4]

Standards Addressed

NGSS Performance Expectations

Earth and Human Activity MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

NRC Disciplinary Core Ideas

ESS3.A: **Natural Resources** Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.

ESS3.C. **Human Impacts on Earth Systems**
Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.
ESS2.C: **The Roles of Water in Earth's Surface Processes**
Water is found in the ocean, rivers, lakes, and ponds. Water exists as solid ice and in liquid form. Nearly all of Earth's available water is in the ocean. Most fresh water is in glaciers or underground; only a tiny fraction is in streams, lakes, wetlands, and the atmosphere. Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and form underground formations. Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. Global movements of water and its changes in form are propelled by sunlight and gravity.

NRC Scientific and Engineering Practices

Practice 1. Asking questions and defining problems
1A: Ask questions to identify and clarify evidence of an argument.
1B: Ask question to identify and/or clarify evidence and/or the premise(s) of an argument
Practice 4. Analyzing and interpreting data
4A: Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.
4B: Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships.
4D: Analyze and interpret data to provide evidence for phenomena.
4G: Analyze and interpret data to determine similarities and differences in findings.
Practice 6: Constructing explanations and designing solutions
6A: Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.
Practice 7. Engaging in argument from evidence
7C: Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.

NRC Crosscutting Concepts

Patterns
1B: Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems.
1C: Patterns can be used to identify cause and effect relationships.
1D: Graphs, charts, and images can be used to identify patterns in data.
Cause and Effect
2B: Cause and effect relationships may be used to predict phenomena in natural or designed systems.
2C: Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.
Scale, Proportion, and Quantity
3A: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
Systems and Systems Models
4A: Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.
Stability and Change
7B: Small changes in one part of a system might cause large changes in another part.
7C: Stability might be disturbed either by sudden events or gradual changes that accumulate over time.
7D: Systems in dynamic equilibrium are stable due to a balance of feedback mechanisms

CSTA K-12 Computer Science Standards

CT	Modeling & simulation	2-9	Interact with content-specific models and simulations to support learning and research.
CT	Modeling & simulation	2-10	Evaluate the kinds of problems that can be solved using modeling and simulation.
CT	Modeling & simulation	2-11	Analyze the degree to which a computer model accurately represents the real world.
CT	Modeling & simulation	3A-8	Use modeling and simulation to represent and understand natural phenomena.

2

Lesson 2

Math Basics for Modeling and the Water Pumping Base Model

50 minutes (1 day)

Lesson Overview (New Learning and Exploration)

In this lesson, students will become familiar with the Water Pumping base model. In the first activity students will review math basics necessary for understanding the model. In the second activity students will decode the base model and run simple experiments, make observations, and identify a complex systems characteristic of the model. In the third activity, students will add an evaporation slider, and then will run an experiment, using the slider. Finally, students will be asked to think of ways to improve the model, based on what they know about the hydrologic cycle and water as a resource.

Teaching Summary

Getting Started – 5 minutes

1. Review of the previous day's lesson and concepts. Connection to today's lesson.

Activity #1: Math Basics for Modeling – 15 minutes

2. Review coordinates on a graph; connect coordinate system to Spaceland.
3. Create turtles in different quadrants of Spaceland and use new blocks to make turtles move in a specific direction.

Activity #2: Inspecting the Water Pumping Model – 10 minutes

4. Identify familiar coding blocks
5. Decode model in pairs.

Activity #3: Adding a Slider for Evaporation Rate – 15 minutes

6. Add a slider for evaporation rate.
7. Run an experiment using the evaporation slider.
8. Discuss the results and relate them to the hydrologic cycle.

Wrap-Up – 5 minutes

9. Discuss limitations of the model and think of ways of improving it.

Lesson Objectives

The student will:

✓ Identify an emergent pattern in the water pump model [LO5].
✓ Learn that water continually cycles among land, ocean, and atmosphere [LO6].
✓ Identify abstractions made and limitations of the model [LO7].
✓ Use the Water Pumping base model to conduct a repeated experiment and make observations (drawing simple correlations) [LO8].
✓ Decode a model [LO9].
✓ Trace a program's execution [LO10].

Teaching Guide

Materials, Resources and Preparation

For the Students

- Computers
- Water Pumping StarLogo Nova base model
- Coordinates and Headings in StarLogo Nova [student handout]
- Model Observation Form [student handout]
- Scientific Practices with Computer Modeling & Simulation [student handout]
- Experimental Design Form document [student handout]
- New commands and concepts sheet [student handout]

For the Teacher

- Computer and projector
- Water Pumping StarLogo Nova models: base model, base model plus evaporation.
- StarLogo Nova Blocks CS Concepts guide document [for reference]
- StarLogo Nova Blocks Reference Guide [for reference]
- Slide presentation with simple commands

Getting Started - 5 mins

1. **Review of the previous day's lessons and concepts**
   - What do you remember from the video? [Refer to Lesson 1.] (DCI: The Role of Water in Earth's Surface Processes) (DCI: Human Impacts on Earth Systems)
   - Can anyone summarize what happened during our game sharing water? [Refer to Lesson 1.] (Practice: Constructing Explanations and Designing Solutions)
   - What do you remember from the Water Pumping model? What elements were modeled in it? [Have the students open the Water Pumping model in pairs and identify elements; refer to Lesson 1.] (Practice: Developing and using models)

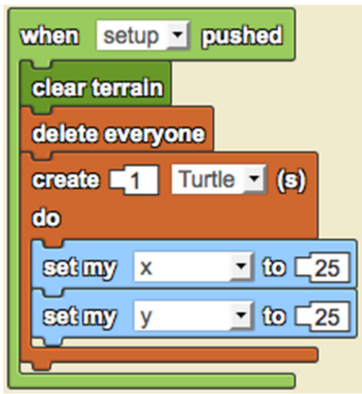
Activity #1: Math Basics for Modeling - 15 mins

In this activity, the students will connect their prior understanding of graphing to the green Spaceland of StarLogo Nova. The coordinate system of Spaceland has (0,0) in the center and expands 50 blocks in all directions. Students will practice placing their turtles in specific quadrants of Spaceland using set traits block called 'set my…' Students will then use the 'set my heading to' block to explore having turtles move in specific directions in Spaceland. These commands were used to make the water molecules move as if responding to gravity. (Practice:

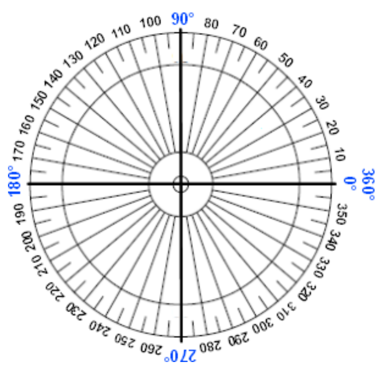
Using Mathematics and Computational Thinking)

2. **Review coordinates on a graph; connect coordinate system to Spaceland.**
    - Review X and Y axes as horizontal and vertical and review where (0,0) is in Spaceland.
    - Demonstrate to students how to set an agent at (0,0)

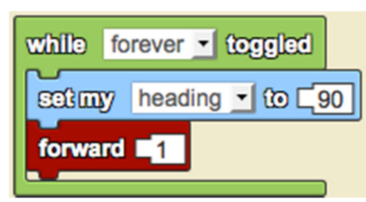
3. **Create turtles in different quadrants of Spaceland and add new blocks to have the turtles move in a specific direction.**



- Have students add code to the 'when setup pushed' block. First they must clear everything that was there before and then add a turtle with specific X and Y coordinates.
- Next, students should add to the setup code by adding 3 more 'create 1 turtle' with new X and Y coordinates.
- Students should be able to put a turtle in each of the 4 quadrants using the 'set my' blocks.



- Now students will use the 'when forever toggled' block to get their turtles moving in a specific direction on Spaceland. The directions follow 360 degrees like a protractor.
- Have students get their turtles to all move towards the top of Spaceland. To do this they will need the code as seen below.



Activity #2: Inspecting the Water Pumping Model - 10 mins

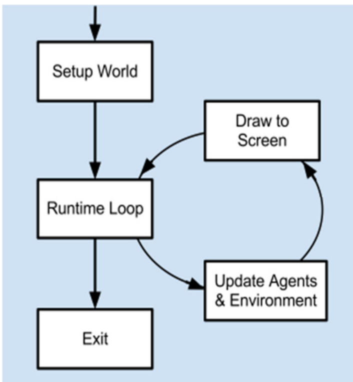
4. **Review familiar and new command blocks.**
    - Keep track of familiar command blocks. Students can refer to their StarLogo Nova Command Blocks and CS Concepts reference sheets from Module 1.
    - Review what the new command blocks do [New commands and concepts sheet].
    - As a group, look at the different sections of code for the Water Pump model.

5. **Assign a part to decode to each pair of students.**
    - Assign partners to share a computer.
    - Assign each pair a piece of the model to decode: Pump, Evaporation, Make Sky, Make Pump, Make Earth, Position Groundwater, Groundwater Movement. The detailed

description of what an agent's procedures are can be added to the Model Observation Form.

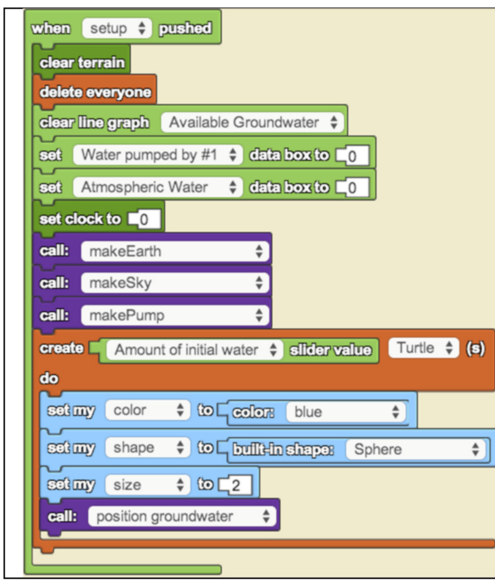
- Give the students 5 minutes to decode, then ask students to share out.

[Note to teachers:] There are three major abstractions in any agent-based model: agents with rules that they follow, the environment in which they coexist, and time. In StarLogo Nova, the first two are easy to see – the agents are the different turtles and the environment is Spaceland.



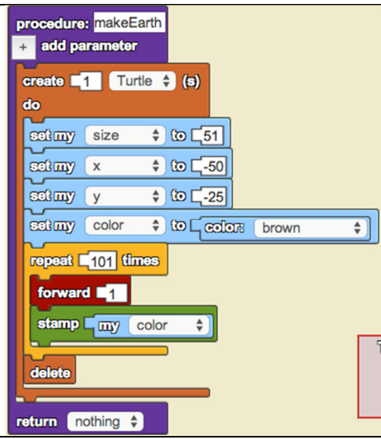
Time is harder to see; instead it can be thought of as a series of time slices or "clock ticks." At each tick, all of the agents have a chance to update their position or state. Ticks or time slices are not the same as seconds because it may take more or less than one second to update all of the agents. In StarLogo Nova, the time model is built into the forever buttons and the collision blocks; each time through the "run loop," every agent gets updated.

Whenever we start looking at a new model we should ask how these three elements of a model have been implemented. A simple way to begin to understand a model is to ask, "Who are the agents?", "How do they behave?", "What is the environment they live in?", and "What happens each time through the run loop?"



When the setup button is pressed, Spaceland is cleared of everything and everyone then clears the parts relating to the graph and data boxes to set them at zero.

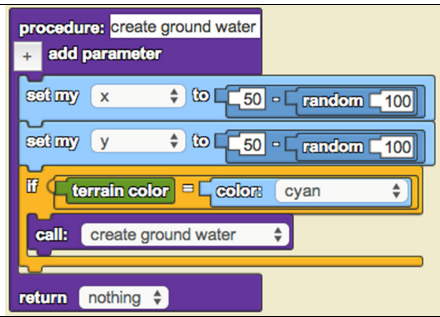
Next, the three procedures are done (MakeEarth, MakeSky and MakePump). The water molecules are created and spread out using a procedure called 'position groundwater.'



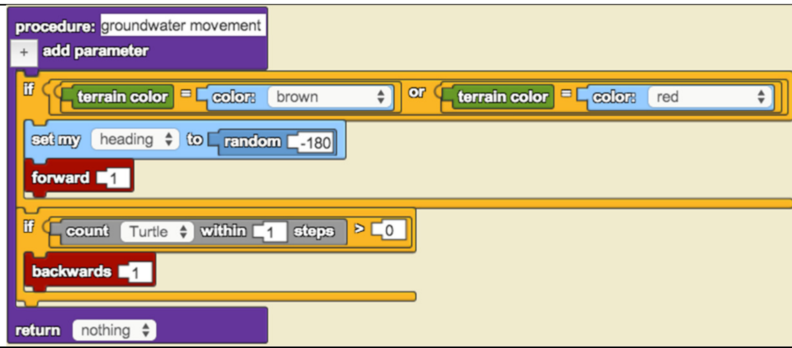
The procedure ‘makeEarth’ has the computer repeat creating a turtle and stamping a brown color on Spaceland. This covers the bottom half of Spaceland with a brown area called Earth.

The procedure ‘makeSky’ has the computer repeat creating a turtle and stamping a cyan blue color on Spaceland. This covers the top half of Spaceland with a cyan blue area called Sky.

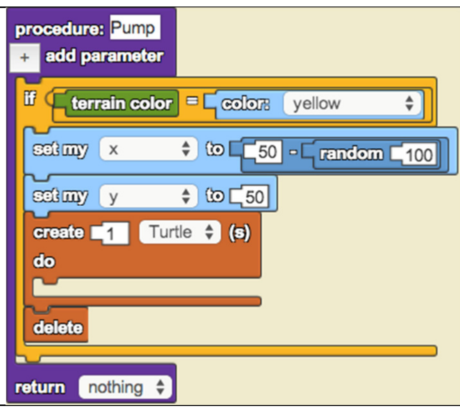
In order to make a red pump with a yellow end, the computer sets its traits to be a certain size, color, facing a certain way, as well as a location on Spaceland. The pump is 50 grid blocks tall plus a 5-block tall area that is yellow. Once the pump is made, the turtle is deleted.



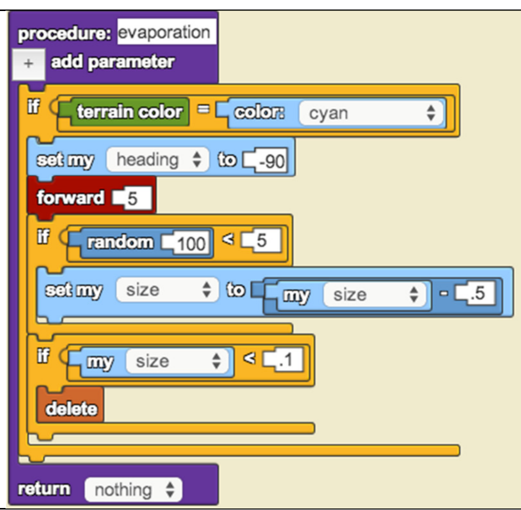
Blue groundwater is created by using a random X and Y coordinate. Groundwater can only be created in the brown Earth area, not in the cyan sky area. If it lands in the cyan sky area it has to do the procedure over again.



Groundwater will move through the brown Earth area by having a random heading downward, and if it lands on top of another water agent, it will jump back one and keep moving



The water will get 'pumped' when the water hits the yellow part of the pump. This means that the water leaves the Earth and goes into the atmosphere. The water is put up at the top of Spaceland and a new water turtle is created, while the original one is deleted.



In the turtle page, water falls from the sky by having its heading down (-90) and it has a 5% chance of getting smaller. If it gets so small, it will disappear.

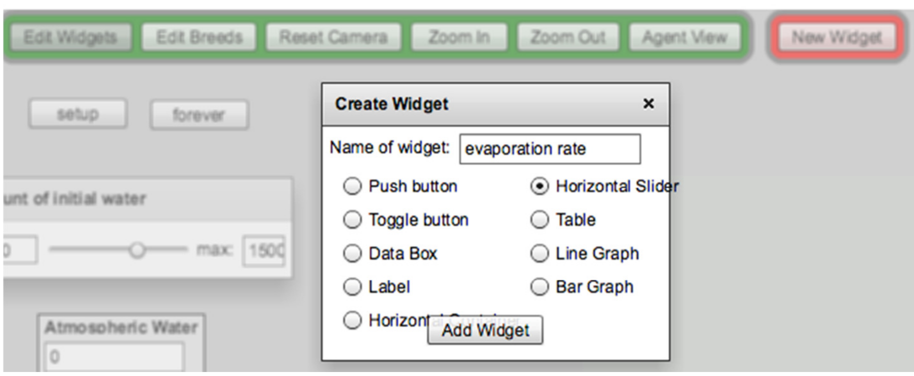
Teaching Tip *The program execution loop can be diagrammed on the board to give visual clues as to what is happening as time advances in the simulation.*

Teaching Tip *The program execution loop can be acted out with a "clock." At each tick, have each student take a turn, before the clock advances. When the clock advances, take a snapshot of the agents' positions at that time. Then flip through the snapshots to see what the computer shows us (discrete time slices).*

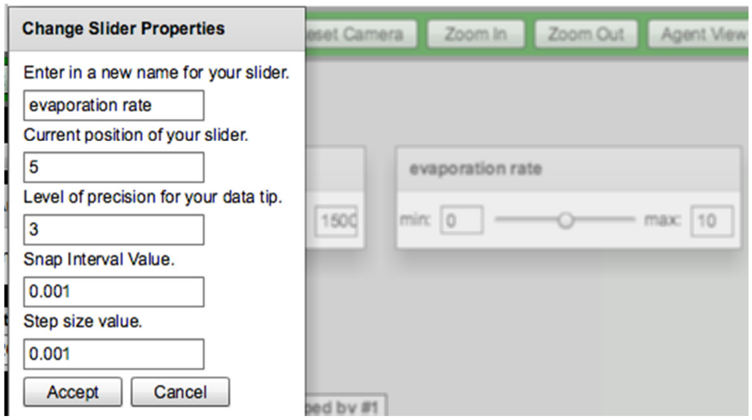
Activity #3: Adding a Slider for Evaporation Rate - 15 mins

In this activity students will add a slider that controls the evaporation rate of water. With the slider, they will be able to will run experiments more efficiently. They should propose questions about the effect of evaporation on the water cycle as modeled here, and they should reflect on the real-world implications of their discoveries. (Practice 1: Asking questions and defining problems) (Practice 2: Developing and using models) (CCC: Patterns)

6. **Add a slider for evaporation.**
   - Have the students remix the model and rename it by adding "mod 1."
   - Review the part of the code that controls evaporation.
   - Ask the students if they can think of a way of changing the evaporation without going to the code.
   - Introduce the **slider** widget.
     Click edit widgets in Spaceland. Add a widget in Spaceland - slider - and give it a name.

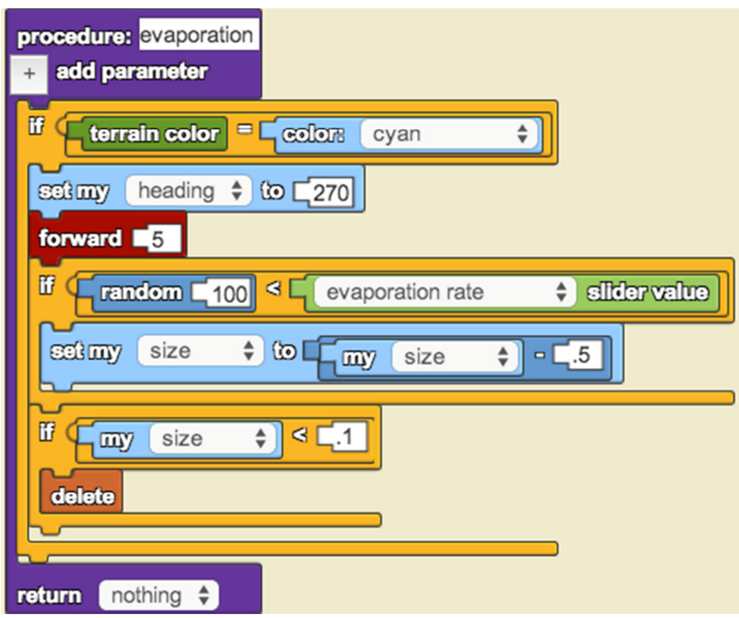


Ask the students if they could use this for changing the evaporation WHILE running the model, WITHOUT going to the code.



Change the maximum and minimum and step size for the evaporation, a rate of 100 is usually good. (Double click on the slider.) Click "edit widgets" again to get out of the editing widgets mode.

- Ask the students to run the code.
  Does it work? Why not? Check the code for the evaporation procedure. It's still the same. We need to change the code here too, not just by adding a widget.



- Find the slider block and add it to the code. Give it the correct name (of the widget we already added).
- Save and run the code again. Change the evaporation on the slider. Has anything happened?

7. Run an experiment using the evaporation slider.

- Now that it's easy to change the evaporation we can run an experiment! We can observe the system from the global perspective to see the relationship between evaporation rate and the availability of water, as well as some of the dynamics of the hydrologic cycle.

(CCC: Scale, proportion, and quantity)

- Use the “Experimental Design” form as a guide and guide students as they develop a scientific question while working in pairs. Emphasize the need to use multiple trials at each setting and to clearly identify the variables, as well as the difference between a question and a *testable* question.
- Run your experiment in pairs so the question can be answered. Which variable will you be changing? What range? How many trials at each setting? This information should be written into their template documents before beginning.
- Collecting and analyzing data. Using the instrumentation in the model (the graph and the data boxes) to monitor the amount of groundwater under the different scenarios you are testing. Record the data. Look for patterns in your data [draw a graph and/or make a table, record observations]. (CCC: Patterns)

8. **Discuss the results and relate them to the hydrologic cycle.**
   - Share out your experimental results.
   - Did the experiment work as you expected?
   - What do you think will happen if we run out of groundwater? (Practice 1: Asking questions and defining problems)

Wrap-Up - 5 mins

9. **Discuss limitations of the model and ask students to think of ways of improving it as homework.**
   - What’s missing from this Water Pumping model? (Practice 2: Developing and using models)
   - How do humans influence the hydrologic cycle?
   - How can we add water sharing and infiltration to our model? (Practice 1: Asking questions and defining problems) Discuss adding more pumps as well as changing how the water moves through the earth.

Assessment Questions

- What is an emergent pattern being formed when we run the model? [LO5]
- Identify which part(s) of the water cycle is represented in the Water Pumping model? [LO6]
- What are some of the abstractions or simplifications made in the model? [LO7]
- What were some of the observations you made as you ran the model? [LO8]
- Name three blocks of code you recognized and what each one does [LO9].
- List the steps the program executes in order in the forever loop [LO10].

Standards Addressed

NRC Disciplinary Core Ideas

ESS3.C. **Human Impacts on Earth Systems** Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth’s environments can have different impacts (negative and positive) for different living things. Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.

NRC Scientific and Engineering Practices

Practice 1. Asking questions and defining problems
1A: Ask questions that arise from careful observation of phenomena, models, or unexpected
1B: Ask questions to identify and clarify evidence of an argument.
1C: Ask questions to determine relationships between independent and dependent variables and relationships in models.
1D: Ask questions to clarify and/or refine a model, an explanation, or an engineering problem.
1F: Ask questions that can be investigated within the scope of the classroom, outdoor environment, and based on observations and scientific principles.
Practice 2. Developing and using models
2A: Evaluate limitations of a model for a proposed object or tool.
2B: Develop or modify a model—based on evidence – to match what happens if a variable or component of a system is changed.
2C: Use and/or develop a model of simple systems with uncertain and less predictable factors.
2D: Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.
2E: Develop and/or use a model to predict and/or describe phenomena.
2G: Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.
Practice 3. Planning and carrying out investigations
3A: Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.
3B: Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.
3D: Collect data to produce data to serve as the basis for evidence to answer scientific questions or test.
Practice 4. Analyzing and interpreting data
4A: Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.
4B: Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships.
4D: Analyze and interpret data to provide evidence for phenomena.
4F: Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials).
4G: Analyze and interpret data to determine similarities and differences in findings.
Practice 5. Using Mathematics and Computational Thinking
5D: Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.
Practice 6. Constructing explanations and designing solutions
6A: Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.
6B: Construct an explanation using models or representations.
6E: Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.
6F: Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.
Practice 7. Engaging in argument from evidence
7C: Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.
Practice 8. Obtaining, evaluating and communicating information
8E: Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations.

NRC Crosscutting Concepts

Patterns
1C: Patterns can be used to identify cause and effect relationships.
1D: Graphs, charts, and images can be used to identify patterns in data.
Cause and Effect
2B: Cause and effect relationships may be used to predict phenomena in natural or designed systems.
2C: Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability
Scale, proportion and quantity
3A: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
Systems and Systems models
4A: Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.
4B: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems.
4C: Models are limited in that they only represent certain aspects of the system under study.
7C: Stability might be disturbed either by sudden events or gradual changes that accumulate over time.

CSTA K-12 Computer Science Standards

CT	Abstraction	2-12	Use abstraction to decompose a problem into sub problems.
CT	Abstraction	3A-9	Discuss the value of abstraction to manage problem complexity.
CT	Connections to other fields	2-15	Provide examples of interdisciplinary applications of computational thinking.
CT	Data representation	2-8	Use visual representation of problem state, structure and data.
CT	Data representation	3A-12	Describe how mathematical and statistical functions, sets, and logic are used in computation.
CT	Modeling & simulation	1:6-4	Describe how a simulation can be used to solve a problem.
CT	Modeling & simulation	2-9	Interact with content-specific models and simulations to support learning and research.
CT	Modeling & simulation	2-11	Analyze the degree to which a computer model accurately represents the real world.
CT	Modeling & simulation	3A-8	Use modeling and simulation to represent and understand natural phenomena.
CT	Modeling & simulation	3B-8	Use models and simulation to help formulate, refine, and test scientific hypotheses.
CT	Modeling & simulation	3B-9	Analyze data and identify patterns through modeling and simulation.
CPP	Data collection & analysis	2-9	Collect and analyze data that are output from multiple runs of a computer program.
CPP	Data collection & analysis	3B-7	Use data analysis to enhance understanding of complex natural and human systems.
CPP	Data collection & analysis	3B-8	Deploy various data collection techniques for different types of problems.
CPP	Programming	3A-3	Use various debugging and testing methods to ensure program correctness.

Lesson 2 - Student Activity #2 Guide

Inspecting the Water Pumping Model

Look under the Hood
Now we are going to get to know the code that makes up the base model!

1) Open your saved StarLogo Nova Water Pumping base model.

2) Navigate to the code section.

3) Use the **Model Observation Form** as you and your programming partner take turns looking at the code. (Remember to use your **driver** and **navigator** roles and switch roles from time to time.) Complete the form by running the model and looking at the code.

4) Which part of the code have you and your partner been assigned?

5) Write down what the code in your assigned section does.

6) Diagram the program's execution loop.

Here is a tip:

- You can refer to your StarLogo Nova Command Blocks and CS Concepts reference sheets from Module 1.

Model Observation Form

Name(s): ____Date:____________________

Model name: ____

Abstractions
Who are the Agents? What is the Environment? What are the Interactions? *How much time does the main forever loop represent? (minutes? days? months?)* *What are the variables of interest?*
Automation
What happens each time through the forever (or main) loop?
Assumption(s)
What real life elements or behaviors were left out of this model?
Analysis
What patterns did you observe? Do these patterns occur in real-life?

Lesson 2 - Student Activity #3 Guide

Adding a Slider for Evaporation Rate

Adding a Slider
In Activity 2 you edited the code to change the evaporation rate. In this activity you will learn a better way to change the evaporation rate.

1) **REMIX** your model and edit the name to “Water Pumping base model **your name your partner’s name mod1**”
2) Add a slider for the evaporation rate and all necessary code.

3) Write down the slider settings you set.

4) Run an experiment using the evaporation rate slider. Use the **Experimental Design Form** to design your experiment first.

5) Record the data from your experiment and summarize your results.

Here is a tip:

- You can write up your results on a separate piece of paper. You can use graphs and/or tables to help you.

When you are done, upload and share your project.
Don’t forget to put both partners’ names in the project title.

Experimental Design Form

Name(s): ____Date: ______________________

Model name: ____

Question
What is your question?
Variables
What are the dependent and independent variables in your experiment?
Range
What is the range of values you will use for each variable?
Trials
How many trials will you run at each setting? Why?
Prediction
What effect do you think the changes you make will have on the model?
Data Collection
What data will you collect?
Data Analysis
How will you analyze your data? (i.e. look for patterns, compare final values, look at the graph)
Interpretation
What is the answer to your question? How does the analysis of your data help you answer your question?

Scientific Practices with Computer Modeling & Simulation

Name: ____ Date: ______________________

The table below lists scientific practices. Please provide an example of what you did that matches the practice.

Practices:	
Ask questions and define problems	
Develop and use a model	
Plan and carry out an investigation	
Analyze and interpret data	
Use mathematics and computational thinking	
Construct explanations and design solutions	
Engage in argument from evidence	
Obtain, evaluate, and communicate information	

2

Lesson 3

Adding More Water Pumps and Running Experiments

50 minutes (1 day)

Lesson Overview (New Learning and Exploration)

In this lesson, the students will modify the base Water Pumping model to include additional water pumps. In the first activity, the students will add a second water pump that pulls water from the aquifer. Next, students will add monitors and a line graph that collects and displays the cumulative amount of water pumped by each pump. In the second activity, the new model can then be used as an experimental test bed. Students develop a hypothesis, run an experiment, and analyze the results to see what effect the modification had on the system.

Teaching Summary

Getting Started – 5 minutes

1. Review of the previous day's lesson and concepts and connection to today's lesson.

Activity #1: Adding a Water Pump – 20 minutes

2. CS review: find and decode the procedure that creates the initial pump.
3. Duplicate and alter the procedure to create a new pump.
4. Add monitors and line graphs to display and visualize data.
5. Test your model.

Activity #2: Running an Experiment – 20 minutes

6. Designing your experiment.
7. Running your experiments.
8. Collecting and analyzing data.

Wrap-Up – 5 minutes

9. What does the computer model enable us to do that would be difficult in the real world?
10. How could a computer model like the Water Pumping model be used to manage water resources?

Lesson Objectives

The student will:

- ✓ Learn that typically as human populations and consumption of natural resources increase, so do the negative impacts on Earth [LO11].
- ✓ Ask a question that can be answered using the model as an experimental test bed [LO12]. Design and conduct an experiment [LO13].
- ✓ Collect and analyze data to look for patterns [LO14].
- ✓ Modify a simple computer model and display output data using widgets [LO15].
- ✓ Practice Pair Programming and Iterative Design-Implement-Test cycle [LO16].

Teaching Guide

Materials, Resources and Preparation

For the Students

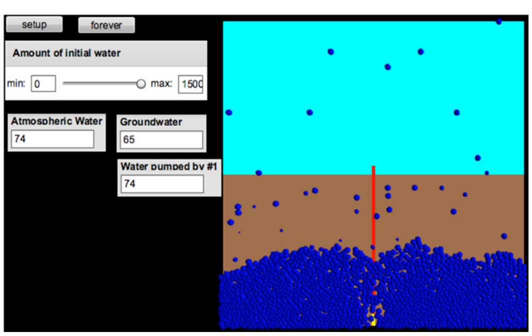
- Computers
- Water Pumping StarLogo Nova base model
- New commands and concepts sheet [student handout]
- Model Design Form document [student handout]
- Experimental Design Form document [student handout]

For the Teacher

- Computer and projector
- Water Pumping StarLogo Nova models: base model, base model plus new pumps
- Water Resources background videos [for reference]
- Guided Introduction to StarLogo Nova document [for reference]
- StarLogo Nova Blocks CS Concepts guide document [for reference]
- StarLogo Nova Blocks Reference Guide [for reference]
- Slide presentation with simple commands

Getting Started - 5 mins

1. **Review of the previous lesson and make connection to today's lesson** – 5 mins
   - Last time we learned about the base model, the abstractions included, and the mechanisms that are executed to make the simulation run. Today we are going to add another pump to the model, then add output widgets so we can assess the impact of the new pump when we run experiments. What do you predict will happen when we add a new pump? (Practice 1: Asking questions and defining problems) (Practice 2: Developing and using models) (CCC: Cause and Effect)
   - Review concepts of infiltration and aquifers.

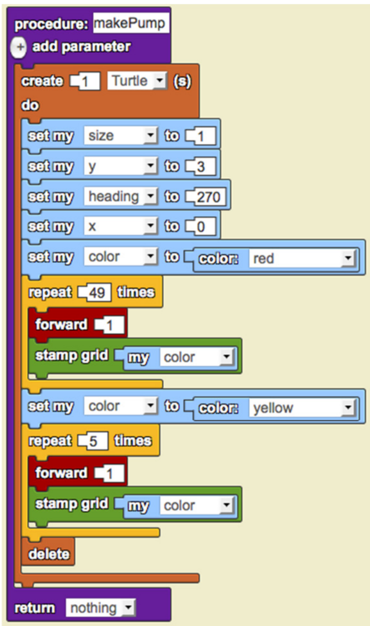


Activity #1: Adding a Water Pump - 20 mins

We'll be adding a new pump that pulls water from the aquifer. Ask the students to review what we know about how the first pump was created. Remember to remix the project before making any changes.

2. CS Review: code and concepts useful for the modification

- Use Think-Pair-Share to have students discuss the existing code and report out.



- [Teacher notes:] Remember that in this model we are using a 2D view of Spaceland, rather than the 3D view.
- In the "makePump" procedure a red turtle is created at (0, 3) and is set to head towards the bottom edge of Spaceland.
- Then the turtle takes 49 steps forward while stamping the grid beneath it red at each step.
- Then the turtle sets its color to yellow and continues 5 more steps forward while stamping the grid beneath it yellow at each step.
- Finally, the turtle is no longer needed so we delete it.

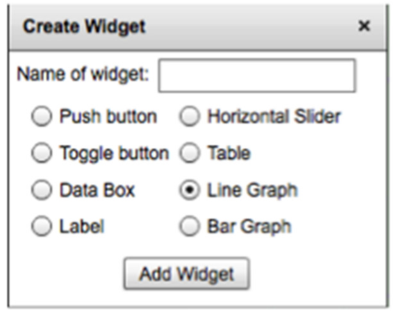
3. Duplicate and alter the procedure to create a new pump

- Ask students for suggestions on how to make a new pump.
- Suggest that we start by making a copy of the existing code for creating a water pump! (n.b. this is a perfect opportunity to talk about remixing on a procedural level.)
- Demonstrate how to use the rectangular lasso to select, copy, and paste a whole code block.
- Give the students the challenge of repositioning the second pump at a distance from the first pump.
- Have the students show their neighbors their solutions to this challenge.
- Next, if time allows, tell the students that we will want to be able to distinguish the number of water particles drawn up by each pump so we will need to be able to tell whether a water molecule is pulled up by one pump or another.
- Have students brainstorm and attempt a solution to this challenge.

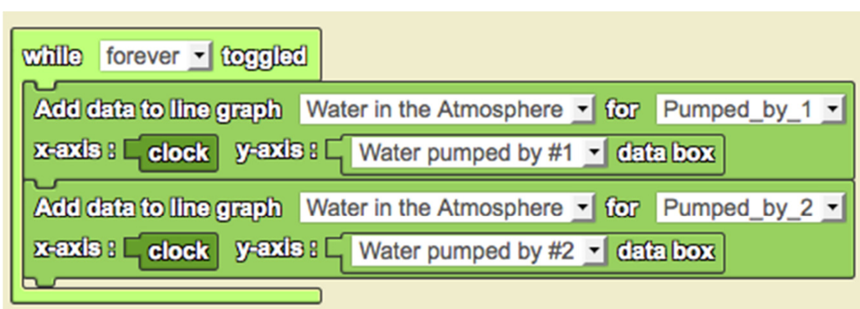
4. Add monitors and line graphs to display and visualize data

- Demonstrate to the students how to use the Edit Widgets tool to add two output data boxes and a line graph (or, alternatively, have a student who knows this technique demonstrate it).
- [Notes for the teacher:] Let's add some instrumentation so we can detect how fast the water is being pumped from each pump head.
- We will start with by adding two monitors, one for the water pumped by the first pump head and one from the new pump head.

- Click the “Edit Widgets” tool in the Spaceland window then click on “Create Widget.”



- Select “Data Box” and then name the widget “Water pumped by #1” and click “Add Widget.” Reposition the widget where it is clearly visible and does not overlap any existing user interface element. Do the same steps to create a widget called “Water pumped by #2.”
- Note: these data boxes can now be used as global variables. The value held in the data box can be updated by any agent.
- Next, add the code that will initialize the values of these data boxes, then increment (or increase) the value anytime an agent interacts with the pump.
- Where do we initialize the values? [in the setup]
- Where do we increment the values? [in the “pump” procedure]
- In order to collect and visualize quantitative data we need to add a line graph in StarLogo Nova. With this information we will be able to compare patterns in the collected data.
- For this model, what products do we want to monitor? [We’d like the graph to collect data on the time elapsed since the model started running and the cumulative number of water molecules pumped by each pump over time.]
- Let’s create a new line graph called “Water Pumped over Time.”
- Demonstrate how to create a line graph in StarLogo Nova using Edit Widgets. Drag the line graph off to the side of Spaceland. Add new series to the graph by double clicking on New Series and changing the name and line color.
- For example,
    - Create a new series called “Pumped_by_1” then select red as its line color.
    - Create a new series called “Pumped_by_2” then select black as its line color.
- Finally, click “Edit Widgets” to leave editing mode and return to play mode.
- Next, we want “The World” to update the line graph each time through the forever loop, so we need to add a “while forever toggled” loop on the page labeled “The World.”



- Notice that we need the “clock” along the x-axis and the cumulative number of water pumped on the y-axis. Where can we get a count of water agents pumped? [The value is held in the “Water pumped by #1” data box already, so use it.]

- Add in similar “Add data to line graph” command blocks to the “while forever toggled” loop for each of the other products you would like to monitor in the line graph.

5. **Test your model**
   - Test your model: Click the “setup” button. Did the value in the “Water pumped by #1” and “Water pumped by #2” data boxes get reset to zero? Click on “forever.” Does the model behave as expected? Is the line graph displaying data? Are the water molecules getting sucked up by the pumps? (Practice 3: Planning and carrying out investigations)

     Teaching Tip *Showing students how to lasso around a block of code then copy and paste that code into a new agent page or the same page can speed up their development time.*

     Teaching Tip *This lesson can be scaffolded based on students' learning abilities by adding or removing the Optional sections. More advanced classes can experiment with additional modifications.*

Additional modifications: (optional)

- Change the pump depth
- Change the pump head surface area
- Add even more pumps

Activity #2: Running an Experiment - 20 mins

In this activity students will run an experiment using the model they have modified by adding another pump. Students will have freedom to design their own experiments and there are many options, from simple to more complex experiments (particularly if students have added in sliders).

6. **Designing your experiment**
   - Experimental Design
     Use the “Experimental Design” form as a guide and guide students as they develop a scientific question in pairs. Emphasize the need to run multiple trials at each setting and to clearly identify the variables, as well as the difference between a question and a *testable* question. (Practice 1: Asking questions and defining problems) (Practice 3: Planning and carrying out investigations) (Practice 5: Using Mathematical and computational thinking)
   - Run your experiment in pairs so the question can be answered. Which variable will you be changing? What range? How many trials will be conducted at each setting? This information should be written into your template documents before beginning.
   - Collecting and analyzing data.
     Using the instrumentation in the model (the graph and the data boxes) to monitor the cumulative number of water molecules pumped over time under the different conditions you are testing. Record the data. Look for patterns in your data [draw a graph and/or make a table, record observations].

7. **Running your experiment**
    - Example simple experiment: Run the experiment for 2400 ticks with a second pump located with x = 25. Hit forever to pause it every 100 ticks. Write down the count of water molecules pumped from each of the data boxes. Repeat the process until you reach approximately 2400 ticks. Then, clear everything and repeat the whole experiment as many times as you think you should. Compare the amounts pumped to the results from the same experiment, when run with just one pump.
    Note: This experiment is just an example among many possible experiments.

8. **Collecting and analyzing data.**
    - Graph your data points. Do you notice any trend? Did the amount of water pumped increase, decrease or stay the same over time with the modification added? What can you say now about your testable idea?
    - Share out your experiment and results with the class.
    - Discuss the difference between **correlation** and **causation**.

    Teaching Tip *The experimental design can be tailored to students' abilities.*

Wrap-Up - 5 mins

8. **What does the computer model enable us to do that would be difficult to do in the real world?**
9. **How could a computer model like this one be used to manage water resources?**

Assessment Questions

- Describe potential negative impacts of adding additional water wells in a community with limited water resources [LO11].
- Assess student responses on the Model Design Form and Experimental Design Form [LO12, LO13, and LO14].
- Describe a procedure you added to the model [LO15].
- In your own words, describe how you tested and, if necessary, refined your procedure [LO16].

Standards Addressed

NGSS Performance Expectations

Earth and Human Activity MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems. **Earth's Systems** MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.

NRC Disciplinary Core Ideas

ESS2.C: **The Roles of Water in Earth's Surface Processes** Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. Global movements of water and its changes in form are propelled by sunlight and gravity. ESS3.C. **Human Impacts on Earth Systems** Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.

NRC Scientific and Engineering Practices

Practice 1. Asking questions and defining problems
Ask questions to identify and clarify evidence of an argument.
Practice 2. Developing and using models
Evaluate limitations of a model for a proposed object or tool.
Develop and/or use a model to predict and/or describe phenomena.
Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.
Practice 3. Planning and carrying out investigations
Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.
Collect data to produce data to serve as the basis for evidence to answer scientific questions or test.
Practice 4. Analyzing and interpreting data
Analyze and interpret data to provide evidence for phenomena.
Practice 7. Engaging in argument from evidence
Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.
Practice 8. Obtaining, evaluating and communicating information
Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations.

NRC Crosscutting Concepts

Cause and Effect
Cause and effect relationships may be used to predict phenomena in natural or designed systems.
Stability and Change
Stability might be disturbed either by sudden events or gradual changes that accumulate over time.
Energy and Matter
The transfer of energy can be tracked as energy flows through a designed or natural system.
Patterns
Patterns can be used to identify cause and effect relationships.
Graphs, charts, and images can be used to identify patterns in data.
Scale, proportion and quantity
Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
Systems and Systems models
Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.
Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems.
Models are limited in that they only represent certain aspects of the system under study.

CSTA K-12 Computer Science Standards

CT	Abstraction	2-12	Use abstraction to decompose a problem into sub problems.
CT	Abstraction	3A-9	Discuss the value of abstraction to manage problem complexity.
CT	Abstraction	3B-10	Decompose a problem by defining new functions and classes.
CT	Algorithms	2-4	Evaluate ways that different algorithms may be used to solve the same problem.
CT	Modeling & simulation	1:6-4	Describe how a simulation can be used to solve a problem.

CT	Modeling & simulation	2-11	Analyze the degree to which a computer model accurately represents the real world.
CT	Modeling & simulation	2-9	Interact with content-specific models and simulations to support learning and research.
CT	Modeling & simulation	3A-8	Use modeling and simulation to represent and understand natural phenomena.
CT	Modeling & simulation	3B-8	Use models and simulation to help formulate, refine, and test scientific hypotheses.
CT	Modeling & simulation	3B-9	Analyze data and identify patterns through modeling and simulation.
CPP	Programming	2-5	Implement a problem solution in a programming environment using looping behavior, conditional statements, logic, expressions, variables and functions.
CPP	Programming	3A-3	Use various debugging and testing methods to ensure program correctness.
CPP	Programming	3A-4	Apply analysis, design and implementation techniques to solve problems.

Lesson 3 - Student Activity #1 Guide

Adding a Water Pump

In this activity, you will be adding a new pump that pulls water from the aquifer. Review what you know about how the first pump was created.

1. Open up your version of the base model. **REMIX** and rename the project with ***your name your partner's name*** **mod3**"

2. Use the **Model Design Form** to plan your modification.

3. Get coding!

4. Test your model to make sure it is working correctly.

Here are a few tips:

- Remember to use the **driver** and **navigator** roles and switch with your programming partner regularly.
- Ask for help if you need it.

When you are done, upload and share your project.
Don't forget to put both partners' names in the project title.

Lesson 3 - Student Activity #2 Guide

Running an Experiment

In this activity you will use your new model to run an experiment.

1. Use the **Experimental Design Form** to plan your experiment.

2. Record your data and analyze your results.

Here is a tip:

- You can write up your results on a separate piece of paper. You can use graphs and/or tables to help you.

Experimental Design Form

Name(s): ____ Date: _________________

Model name: ____

Question
What is your question?
Variables
What are the dependent and independent variables in your experiment?
Range
What is the range of values you will use for each variable?
Trials
How many trials will you run at each setting? Why?
Prediction
What effect do you think the changes you make will have on the model?
Data Collection
What data will you collect?
Data Analysis
How will you analyze your data? (i.e. look for patterns, compare final values, look at the graph)
Interpretation
What is the answer to your question? How does the analysis of your data help you answer your question?

Model Design Form

Name(s): ____ Date: ___________

Model name: ____

MODEL DESCRIPTION
What will be modeled?
What abstractions are used?
What do the agents represent? *What does the space or environment represent?* *What are the <u>Interactions</u>?* *How much time does the main forever loop represent? (minutes? days? months? years?)* *What are the assumptions made? What real life elements or behaviors were left out of this model?*
How will it be modeled?
What happens when simulated time advances?

2

Lesson 4

Customize your Water Pumping Model

50 minutes (1 day)

Lesson Overview (New Learning and Exploration)

In this lesson, students design their own Water Pumping projects consisting of a question, experimental design and model. In the first activity, students will learn about computational science and how to design a model, and will use this knowledge to scope their project. This leads to a second activity, in which they start designing and implementing their model, using the Water Pumping base model as a starting place.

Teaching Summary

Getting Started – 5 minutes

1. Review of the previous day's lesson and concepts and connection to today's lesson

Activity #1: Computational Science and Designing Your Project – 20 minutes

2. Introduce key components of the computational science process
3. Define your computational science project

Activity #2: Designing and Developing Your Model – 20 minutes

4. Agents and environment
5. Interactions

Wrap-Up – 5 minutes

6. What research is necessary to ground your model in reality?
7. How will you check to see if your model is realistic?

Lesson Objectives

The student will:

- ✓ Learn that resources are distributed unevenly around the planet as a result of past geologic processes [LO17].
- ✓ Learn that Humans depend on water resources and many of these resources are not renewable or replaceable over human lifetimes [LO18].
- ✓ Use the key stages of computational science and Project Design Form to develop a question,

create a model, and design an experiment [LO19].
- ✓ Implement problem solutions using looping behavior, conditional statements, logic, expressions, variables and functions [LO20].

Teaching Guide

Materials, Resources and Preparation

For the Students

- Computers
- Water Pumping StarLogo Nova model
- New commands and concepts sheet [student handout]
- Project Design Form [student handout]
- Experimental Design Form document [student handout]
- Scientific Practices with Computer Modeling & Simulation document [student handout]

For the Teacher

- Computer and projector
- Water Pumping StarLogo Nova models: base model, base model plus pumps.
- Water Resources background videos [for reference]
- Guided Introduction to StarLogo Nova document [for reference]
- StarLogo Nova Blocks CS Concepts guide document [for reference]
- StarLogo Nova Blocks Reference Guide [for reference]
- Slide presentation with simple commands

Getting Started - 5 mins

1. **Review of the previous day's lessons and concepts and connection to today's lesson**
    - Last time we added another pump to the Water Pumping base model, and used the model as an experimental test bed to see the impact of additional water consumers on the aquifer. What did we learn? (DCI: Human impacts on Earth Systems)
    - Today, using what you've learned in the first three lessons on water resources and computational science, you'll come up with your own modifications in teams.

Activity #1: Computational Science and Design Your Project - 20 mins

In this activity, the teacher will introduce the key aspects of designing a model for computational science. Students will work together in teams to develop their questions and projects. Students should be given creative freedom, within the scope of investigating and modeling a local condition impacting water supply or quality.

2. **Introduce key components of the computational science process**
    - Computational scientists in STEM fields have a process when designing models for computational science. They go back and forth between different stages within this overall process.
    - Key stages of this process are:
        - *Select a real-world problem to study.*
          Discuss what makes a problem suitable for studying using computational methods. Make simplifications to the model through abstraction. Answer "What real world

issue are you interested in investigating? What are measurable aspects of the problem?" and check that the question you ask could be answered through modeling and simulation. (CCC: Systems and systems models)

- *Simplify the scope of the model using abstraction*.
  What aspects of the problem are important to model? Narrow the scope of the problem to one that can be modeled, given the time and computing resources available. Diagram the model components and the simulation loop.
- *Convert your diagram of the model into a computational model*.
  Use fundamental concepts in CS. Design and implement algorithms that will be needed. [An iterative Design-Implement-Test process is used when developing the model.]
- *Parameterize the model*.
  Describe the range of values and increments for the variables and parameters in your experimental design. Describe the collection and analysis of data output from models.
- *Simulate and collect data*.
  Use the computational model as a test bed for running experiments.
- *Analyze/Interpret*.
  Search for patterns in your data. Discuss your findings and whether or not they constitute "proof" or help you answer your question. Discuss the limitations of the computer model, what assumptions were made, and what the model tells us, if anything, about the real world.
- *Repetition*.
  While working through the different stages, we often find verification errors (bugs in the code) or validation errors (when comparing model behavior to real world data, there are differences that suggest that the wrong assumptions or simplifications were made). When this happens, we revisit the necessary stages to refine and improve our model.
- *Share your model and findings.*

• If time allows, refer to the Water Pumping model as an example when describing these stages.

3. Define your computational science project

• Hand out the Project Design Form to students in teams or pairs. (Practices 1-8 are fulfilled throughout Activity #1 and #2).
• Discuss local/regional factors such as rainfall, soil types, pollution, or regulations that may affect water supply or water quality. (CCC: Patterns) (CCC: Cause and Effect)
• Have students specify their question and describe the model and experimental design on the form. Encourage students to use research to inform their model design.

  [As an example, we might add regions with soil of different porosity (clay, dirt, gravel, etc.) to the model. Have water move through different regions at different speeds.]
  [As an example, we might add restrictions on water pumping such that after a limit is reached by a pump, the pumping turns off thereby allowing other pumps to continue unabated.]

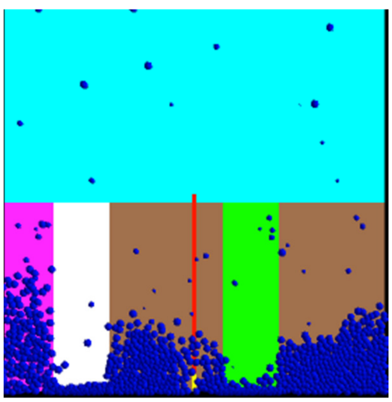
  Teaching Tip *Students should be encouraged to develop their own Water resource questions they would like to address with their models. The teacher should help them* *simplify their questions to ensure they will be able to create an appropriate model.*

Activity #2: Designing and Developing Your Model - 20 mins

In this activity, students will work in pairs using the pair programming technique to design and develop their chosen model, by working from their planning worksheets and their StarLogo Nova Blocks and CS Concepts reference guides. [The example provided below shows how to regions of different soil types.]

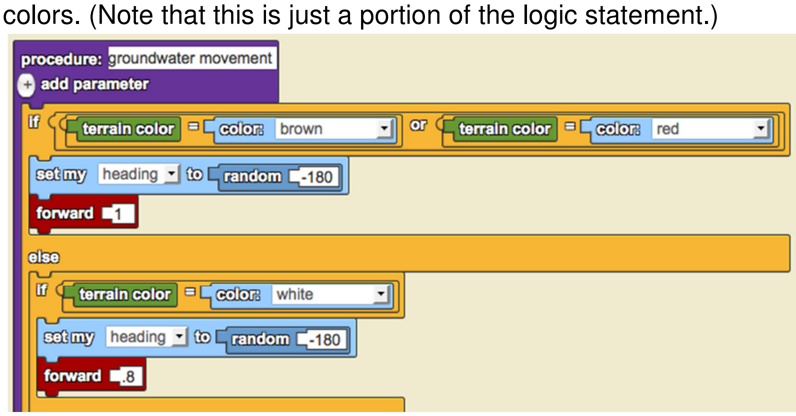
4. Agents and Environment

- The students should first create code that adds in their agents and any modifications to the environment they want. The setup code in “The World” page is usually used for setting up the environment and populating the environment with agents. In the example of creating regions of different porosity, the following steps would be necessary:
  - Create an agent who will stamp a region of a different color.
  - Create a procedure (called from within the “when setup pushed” procedure) that instructs the agent to walk with pen down to change the terrain color in places. When the area is colored then the agent can be deleted.



5. Interactions

- The students should then create code that instructs an agent what to do when it interacts with other elements in the environment or with other agents. Below is an example of instructing agents how to interact when they are stading on terrain patches of different colors. (Note that this is just a portion of the logic statement.)



  - Run the code and test it. Do the elements of the model behave how you think they should? Be sure to test the range of values for each variable (such as evaporation rate and number of water agents).

Teaching Tip *There are many different levels of coding that can take place in this activity. More advanced learners could incorporate several modifications at once – e.g. adding two types of soils with different porosity, changing the rates at which water is recharging the aquifer, adding some element that partially blocks the flow of the water in the ground, create areas on the surface of the ground that are not permeable to water (example is asphalt or concrete), adding plants that use water before the water enters the aquifer. Students need to understand how to test and experiment with these models as well as how to code them. Less advanced learners should at least achieve adding additional pumps at various depths so they can experiment in the next lesson. Students should be encouraged to think for themselves.*

Wrap-Up - 5 mins

6. **What research is necessary to ground your model in reality?**
7. **How will you check to see if your model is realistic?**

Teaching Tip *Encourage the students to differentiate between reality and their models, while at the same time encouraging them to do research to make their model more realistic.*

Assessment Questions

- Give three examples of how local conditions affect water supply or quality [LO17].
- Describe why some water is not renewable or replaceable; where does the water go? [LO18]
- See student Project Design Form. (Did student choose a question appropriate for answering with the model? Could student explain why it was chosen? Did student describe the aspects of the real world to be included in the model and why they were selected? etc.) [LO19]
- Describe procedures in the model that you built. Choose one and describe how it works in detail [LO20].

Standards Addressed

NGSS Performance Expectations

Earth and Human Activity MS-ESS3-3.Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment. MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

NRC Disciplinary Core Ideas

ESS3.C. **Human Impacts on Earth Systems** Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.

NRC Scientific and Engineering Practice Standards

Practice 1: Asking questions and defining problems
1A: Ask questions that arise from careful observation of phenomena, models, or unexpected results.
1D: Ask questions to clarify and/or refine a model, an explanation, or an engineering problem.
1E: Ask questions that require sufficient and appropriate empirical evidence to answer.

Practice 2: Developing and using models
2A: Evaluate limitations of a model for a proposed object or tool.
2B: Develop or modify a model—based on evidence – to match what happens if a variable or component of a system is changed.
2C: Use and/or develop a model of simple systems with uncertain and less predictable factors.
2D: Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.
2E: Develop and/or use a model to predict and/or describe phenomena.
2F: Develop a model to describe unobservable mechanisms.
2G: Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.

Practice 3: Planning and carrying out investigations
3A: Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.
3B: Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.

Practice 4: Analyzing and interpreting data
4A: Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.
4B: Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships.
4F: Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials).

Practice 5: Using mathematics and computational thinking
5A: Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends.
5B: Use mathematical representations to describe and/or support scientific conclusions and design solutions.
5C: Create algorithms (a series of ordered steps) to solve a problem.
5D: Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.

Practice 6: Constructing explanations and designing solutions
6E: Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.
6F: Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.

Practice 7: Engaging in argument from evidence
7C: Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.

Practice 8: Obtaining, evaluating, and communicating information
8C: Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence.

NRC Crosscutting Concepts

1. Patterns:
1C: Patterns can be used to identify cause and effect relationships.

2. Cause and Effect:
2B: Cause and effect relationships may be used to predict phenomena in natural or designed systems.

4. Systems and Systems models
4B: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems.
4C: Models are limited in that they only represent certain aspects of the system under study.

CSTA K-12 Computer Science Standards

CT	Abstraction	2-12	Use abstraction to decompose a problem into sub problems.
CT	Abstraction	3A-9	Discuss the value of abstraction to manage problem complexity.
CT	Abstraction	3B-10	Decompose a problem by defining new functions and classes.
CT	Algorithms	3A-3	Explain how sequence, selection, iteration and recursion are the building blocks of algorithms.
CT	Modeling & simulation	1:6-4	Describe how a simulation can be used to solve a problem.
CT	Modeling & simulation	2-10	Evaluate the kinds of problems that can be solved using modeling and simulation.
CT	Modeling & simulation	2-11	Analyze the degree to which a computer model accurately represents the real world.
CT	Modeling & simulation	3A-8	Use modeling and simulation to represent and understand natural phenomena.
CT	Modeling & simulation	3B-8	Use models and simulation to help formulate, refine, and test scientific hypotheses.
CPP	Programming	2-5	Implement a problem solution in a programming environment using looping behavior, conditional statements, logic, expressions, variables and functions.
CPP	Programming	3A-4	Apply analysis, design and implementation techniques to solve problems.

Lesson 4 - Student Activity #1 Guide

Computational Science and Designing Your Project

Design your project

In this activity you and your programming partner will come up with your own model based on the Water Pumping base model.

5. Open up your version of the base model. **REMIX** and rename to "Water Pumping ***your name your partner's name*** **NEW**"

6. Use the **Project Design Form** to plan your modeling.

Here is a tip:

- Try to think of things to put in your model that will help you answer your question, but keep it simple!

When you are done, move on to Activity #2.

Don't forget to put both partners' names in the project title.

Lesson 4 - Student Activity #2 Guide

Designing and Developing Your Model

Code your model
In this activity you and your programming partner will put your planning into practice and you will make your new model.

1. Open up your model ("Water Pumping ***your name your partner's name*** **NEW**")

2. Use the **Project Design Form** to guide you as you take turns **driving** and **navigating**.

Here is a tip:

- You can copy and paste code from other models to help you work more quickly.

When you are done, upload and share your project.
Don't forget to put both partners' names in the project title.

Experimental Design Form

Name(s): ______________________________________ Date: ________________

Model name: ____

Question
What is your question?
Variables
What are the dependent and independent variables in your experiment?
Range
What is the range of values you will use for each variable?
Trials
How many trials will you run at each setting? Why?
Prediction
What effect do you think the changes you make will have on the model?
Data Collection
What data will you collect?
Data Analysis
How will you analyze your data? (i.e. look for patterns, compare final values, look at the graph)
Interpretation
What is the answer to your question? How does the analysis of your data help you answer your question?

Project Design Form

Name(s): ____ Date: ______________

Model name: ____

As you create a computer model of a scientific phenomenon, use this form to help you organize your thoughts and develop the model from start to finish.

PROJECT DESCRIPTION
What question do you seek to answer?
What observation of phenomenon, model, or unexpected result led you to this question?

MODEL DESCRIPTION
What will be modeled?
What question do you seek to answer?
How will it be modeled? What abstractions are used?
Who are the Agents? What is the Environment? What are the Interactions? *How much time will the main forever loop represent? (minutes? days? months? years?)* *What are the parameters of interest?*

EXPERIMENTAL DESIGN
Variables
What are the dependent and independent variables in your experiment?
Range
What is the range of values you will use for each variable?
Trials
How many trials will you run at each setting? Why?
Data Collection
What data will you collect?
Prediction
What effect do you think your variables will have on the model?

Data Analysis
How will you analyze your data?
Interpretation
How does the analysis of your data help you answer your question?
Going further
If you had more time, what further changes would you make to your model?

Scientific Practices with Computer Modeling & Simulation

Name: ______________________________________ Date: _____________

The table below lists scientific practices. Please provide an example of what you did that matches the practice.

Practices:	
Ask questions and define problems	
Develop and use a model	
Plan and carry out an investigation	
Analyze and interpret data	
Use mathematics and computational thinking	
Construct explanations and design solutions	
Engage in argument from evidence	
Obtain, evaluate, and communicate information	

2

Lesson 5

Experiment with Your New Water Pumping Model

50 minutes (1 day)

Lesson Overview (New Learning and Exploration)

In this lesson, students will finish coding their chosen modifications. Students will then debug their code, checking to make sure it works as they intended, and fixing errors as they find them. In the second activity, students will use their new model as an experimental test bed. They will modify the question they came up with in Lesson 4 if necessary, and they will run experiments to address this question, using repeated trials at each variable setting. Students will critically analyze their results, as well as their model, and relate it back to the bigger picture – Water as a Shared Resource. Students will reflect on what modeling water as a shared resource has taught them about resource management and their own actions as water users. Students should share their findings with the whole class.

Teaching Summary

Getting Started – 5 minutes

1. Review of previous day's lesson and concepts and connection to today's lesson
2. Revisit complex adaptive systems concepts

Activity #1: Completing and Debugging Your Code – 15 minutes

3. Use pair programming to complete the model
4. Test the new model – trace execution and debug the model

Activity #2: Running Experiments – 15 minutes

5. Review the question first formulated in the model design
6. Design experiments to run in the new model
7. Run experiments, using multiple trials

Wrap-Up – 15 minutes

8. Analyze results and discuss conclusions
9. Relate the results back to the bigger picture of sharing resources
10. Share your model and experimental results with the class

Lesson Objectives

The student will:

- ✓ Revisit complex adaptive systems concepts and learn how they relate to understanding resource management [LO21].
- ✓ Gain a deeper understanding of impacts on ground water resources through experience creating and experimenting with a water pump model [LO22].
- ✓ Use customized model as an experimental test bed to run experiments [LO23]. Learn that multiple runs of the experiment are needed at each variable setting due to inherent randomness in the model [LO24].
- ✓ Use iterative refinement and apply debugging techniques to isolate and fix errors in code [LO25].

Teaching Guide

Materials, Resources and Preparation

For the Students

- Computers
- Water Pumping with customizations StarLogo Nova model
- Scientific Practices with Computer Modeling & Simulation document [student handout]
- Project Design Form [student handout from Lesson 4]
- New commands and concepts sheet [student handout]

For the Teacher

- Computer and projector.
- Water resources background videos [for reference].
- Water pumping StarLogo Nova models: base model plus sample customizations
- StarLogo Nova Blocks CS Concepts guide document [for reference]
- StarLogo Nova Blocks Reference Guide [for reference]
- Slide presentation with simple commands

Getting Started - 5 mins

1. **Review of previous day's lesson and concepts and connection to today's lesson**
   - During the last lesson you came up with your own design for a model to answer a question you had regarding water pumping. How far along did everyone get in your coding?
   - We will have a chance today to finish our models, check to see if they are working correctly and fix them, and also run an experiment.

2. **Revisit complex adaptive systems**
   - Before starting, briefly revisit the complex adaptive systems concepts of leaderlessness, many agents following simple rules, emergent pattern formation, and unpredictability. Relate these concepts to features of the water pumping model and patterns generated by running our simple model. (CCC: Patterns) (CCC: Cause and Effect) (CCC: Systems and systems models) (CCC: Stability and change)

Activity #1: Completing and Debugging Your Code - 15 mins

In this activity, the programming pairs should work together, alternating pilot and navigator roles, to complete their model and to test and debug it as well. Students will naturally work at different paces, but they should be encouraged to avoid overcomplicating their model and to move on to experimentation as soon as they can. (Practice 3: Planning and carrying out investigations) (Practice 5: Using Mathematical and computational thinking) (Practice 6: Constructing explanations and designing solutions) (CCC: Patterns) (CCC: Scale, proportion, and quantity)

3. **Use pair programming to complete the model**
   - Finish up your model if necessary.

4. **Test the new model – trace execution and debug the model**
   - Each time you finish making a change to your code, test that you have not introduced new bugs and that the elements of the model are behaving as expected.
     Did the elements you created in your setup procedure appear? Did the model behave the way you expected it to?
   - Test your forever loop. Are all of the behaviors you created that you want to run when you toggle forever working as you had hoped?
   - Test your model. Did you create other widgets such as buttons, sliders, graphs and other monitors? Check each of these to make sure they are working correctly.
   - Observe your agents – when they collide, are they following the code you created for them in their collision blocks?

     Teaching Tip *Students may need more or less time to complete their coding than is allotted. Students that finish earlier can move on to Activity 2 (experiments). They should be encouraged to be more thorough in their experimentation.*

Activity #2: Running Experiments - 15 mins

In this activity, students will work on their experiments, following the plan they set out in Lesson 4, editing it as needed. Students should aim to be done with experimentation quickly and working on analyzing their results and preparing them for discussion with the class. (Practice 1-8 are addressed in this activity #2 and the Wrap-Up activity.)

5. **Review the question first formulated in the project design**
   - Check your Project Design Form. Review the question you wrote down. Think about your model. Is it a good question to ask and answer with simulations using your model? If not, change it to match your model.

6. **Design experiments to run in the new model**
   - Check your Project Design Form again. Look at the experimental design you prepared in Lesson 4. Do you think it still works with your model now that it is done? Run one experiment as set out on your Project Design Form and check if you need to change anything. For example, maybe you need to run the simulations for more ticks. Change your design as needed.

7. **Run experiments, using multiple trials**
    - Run your experiments following along with your design. Make sure you write down your results as you go along. Make sure you are running the simulations enough times to take randomness into account.

Wrap-Up - 15 mins

8. **Analyze results and discuss conclusions**
    - Once you have finished your experiments and written down your results, summarize them using a table and/or a graph.
    - Think about the results and what they mean. Write down your thoughts.

9. **Relate the results back to the bigger picture of sharing resources**
    - Now think about the bigger picture. What do your results tell you about sharing resources? Can you make recommendations based on your results for the other students in the class?
    - Write down your “bigger picture” results.

10. **Prepare your model and experimental results for presentation**
    - Have students prepare their models and results in pairs to show to the rest of the class following the guidelines below. They should aim to use presentation tools and a projector.

      Guidelines for students:
      1. State the question you were seeking to answer or the problem that you were studying.
      2. Tell us about any background research you did on the topic.
      3. Tell us about your model (what’s included and what was left out).
      4. Tell us about your experimental design.
      5. Show your model running and how you collected data.
      6. Show any collected data and analysis.
      7. Tell us about any relationships you noticed between variables that help you understand or predict the phenomenon.
      8. Summarize your findings; what was the outcome of running your experiments.
      9. Do you think you learned anything about the real world?
      10. Show us a piece of code you are proud of.
      11. Question and answers.

      Teaching Tip *This lesson could be expanded into a sixth and seventh lesson to allow for more time for the students to prepare, present and discuss their models and results.*

Assessment Questions

- Describe four characteristics of a complex system and how they relate to a resource management situation [LO21].
- What local or regional issue impacting water resources was included in your model? What are some of the potential impacts of that factor or condition? [LO22].
- See student Experimental Design Form [LO23, LO24].
- Give an example of how you were able to find and fix an error you had in your code [LO25].

Standards Addressed

NGSS Performance Expectations

Earth and Human Activity
MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

NRC Disciplinary Core Ideas

ESS3.C. **Human Impacts on Earth Systems**
Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.

NRC Scientific and Engineering Practices

Practice 1: Asking questions and defining problems
1A: Ask questions that arise from careful observation of phenomena, models, or unexpected results.
1D: Ask questions to clarify and/or refine a model, an explanation, or an engineering problem.
1E: Ask questions that require sufficient and appropriate empirical evidence to answer.

Practice 2: Developing and using models
2A: Evaluate limitations of a model for a proposed object or tool.
2B: Develop or modify a model—based on evidence – to match what happens if a variable or component of a system is changed.
2C: Use and/or develop a model of simple systems with uncertain and less predictable factors.
2D: Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.
2E: Develop and/or use a model to predict and/or describe phenomena.
2F: Develop a model to describe unobservable mechanisms.
2G: Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.

Practice 3: Planning and carrying out investigations
3A: Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.
3B: Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.

Practice 4: Analyzing and interpreting data
4A: Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.
4B: Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships.
4F: Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials).

Practice 5. Using Mathematics and Computational Thinking
5A: Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends.
5B: Use mathematical representations to describe and/or support scientific conclusions and design solutions.
5C: Create algorithms (a series of ordered steps) to solve a problem.
5D: Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.

Practice 6. Constructing Explanations and Designing Solutions
6E: Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.
6F: Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.

Practice 7: Engaging in argument from evidence
7C: Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.

Practice 8. Obtaining, evaluating and communicating information
Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations.

NRC Crosscutting Concepts

Cause and Effect
Cause and effect relationships may be used to predict phenomena in natural or designed systems.
Stability and Change
Stability might be disturbed either by sudden events or gradual changes that accumulate over time.
Energy and Matter
The transfer of energy can be tracked as energy flows through a designed or natural system.
Patterns
Patterns can be used to identify cause and effect relationships.
Graphs, charts, and images can be used to identify patterns in data.
Scale, proportion and quantity
Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
Systems and Systems 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.
Models are limited in that they only represent certain aspects of the system under study.

CSTA K-12 Computer Science Standards

CT	Abstraction	2-12	Use abstraction to decompose a problem into sub problems.
CT	Abstraction	3A-9	Discuss the value of abstraction to manage problem complexity.
CT	Abstraction	3B-10	Decompose a problem by defining new functions and classes.
CT	Algorithms	3A-3	Explain how sequence, selection, iteration and recursion are the building blocks of algorithms.
CT	Modeling & simulation	1:6-4	Describe how a simulation can be used to solve a problem.
CT	Modeling & simulation	2-10	Evaluate the kinds of problems that can be solved using modeling and simulation.
CT	Modeling & simulation	2-11	Analyze the degree to which a computer model accurately represents the real world.
CT	Modeling & simulation	3A-8	Use modeling and simulation to represent and understand natural phenomena.
CT	Modeling & simulation	3B-8	Use models and simulation to help formulate, refine, and test scientific hypotheses.
CPP	Programming	2-5	Implement a problem solution in a programming environment using looping behavior, conditional statements, logic, expressions, variables and functions.
CPP	Programming	3A-4	Apply analysis, design and implementation techniques to solve problems.

Lesson 5 - Student Activity #1 Guide

Completing and Debugging Your Code

Debug your model
In this activity you and your programming partner trace execution of your model and use **debugging** to fix any issues you find.

3. Open up your model ("Water Pumping ***your name your partner's name*** **NEW**")

4. Test your model out and fix any issues you find.

Here is a tip:

- Try to look at the code and model in sections to avoid getting overwhelmed.

When you are done, move on to Activity 2.
Don't forget to put both partners' names in the project title.

Lesson 5 - Student Activity #2 Guide

Running Experiments

In this activity, you and your programming partner will use your new model to run experiments.

1. Open up your model ("Water Pumping ***your name your partner's name*** **NEW**")
2. Use your **Project Design Form** to guide your experimentation.
3. Record your results and perform **Data Analysis** on them. Record your conclusions.

Here is a tip:

- You may need to modify your experimental design, now that you have finished your model.

When you are done, start preparing your results for a presentation.
Don't forget to put both partners' names in the project title.

Student Activity Guide

Preparing Presentations

In this activity, you and your programming partner will prepare a ten-minute presentation using tools like slide presentation and a projector. Follow the guidelines below:

1. State the question you were seeking to answer or the problem that you were studying.
2. Tell us about any background research you did on the topic.
3. Tell us about your model (what's included and what was left out).
4. Tell us about your experimental design.
5. Show your model running and how you collected data.
6. Show any collected data and analysis.
7. Tell us about any relationships you noticed between variables that help you understand or predict the phenomenon.
8. Summarize your findings; what was the outcome of running your experiments?
9. Do you think you learned anything about the real world?
10. Show us a piece of code you are proud of.
11. Allow time for questions and answers.

Here is a tip:

- Take turns presenting different sections. Plan on going between the presentation (slide presentation, for example) and the model.

When you are done, practice your presentation with your partner.
Don't forget to put both partners' names in the project title.

Project Design Form

Name(s): ______________________________________ Date: _____________

Model name: ____

As you create a computer model of a scientific phenomenon, use this form to help you organize your thoughts and develop the model from start to finish.

PROJECT DESCRIPTION
What question do you seek to answer?
What observation of phenomenon, model, or unexpected result led you to this question?

MODEL DESCRIPTION
What will be modeled?
What question do you seek to answer?
How will it be modeled? What abstractions are used?
Who are the <u>Agents</u>? What is the <u>Environment</u>? What are the <u>Interactions</u>? *How much time will the main forever loop represent? (minutes? days? months? years?)* *What are the parameters of interest?*

EXPERIMENTAL DESIGN
Variables
What are the dependent and independent variables in your experiment?
Range
What is the range of values you will use for each variable?
Trials
How many trials will you run at each setting? Why?
Data Collection
What data will you collect?
Prediction
What effect do you think your variables will have on the model?

Data Analysis
How will you analyze your data?
Interpretation
How does the analysis of your data help you answer your question?
Going further
If you had more time, what further changes would you make to your model?

Scientific Practices with Computer Modeling & Simulation

Name: ____ Date: ______________

The table below lists scientific practices. Please provide an example of what you did that matches the practice.

Practices:	
Ask questions and define problems	
Develop and use a model	
Plan and carry out an investigation	
Analyze and interpret data	
Use mathematics and computational thinking	
Construct explanations and design solutions	
Engage in argument from evidence	
Obtain, evaluate, and communicate information	