Encouraging Students to Think Critically About Earth's Systems and Sustainability

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Abstract

This article describes how the NSF funded *High-Adventure Science: Earth's Systems and Sustainability (HAS:ESS)* project is developing online curriculum modules for middle school and high school classroom use. The curricula engage students with interactive computational models and analysis of real-world data as they build scientific reasoning and argumentation skills, focused around core ideas in Earth Science with particular emphasis on how humans affect Earth's systems. Currently available modules focus on climate change and on fresh water availability. Additional modules will focus on the future of energy resources, land use and sustainability, and air pollution. In each module, students encounter core Earth Science concepts with respect to human interactions: the water cycle to understand fresh water distribution; the atmospheric greenhouse effect to understand climate change; weather patterns to understand air pollution distribution and inversions, and the rock cycle to understand fossil fuel distribution. Computational models are used as a way to help students more deeply explore complex Earth systems and the human impact on those systems. Students develop a deep understanding of the science as they engage in scientific argumentation: reasoning through real-world data and evidence from their experimentation with models to make claims and subsequently defending their claims with particular pieces of evidence.

Introduction

The overwhelming and expanding presence of humans—nearly seven billion strong—is having a pronounced impact on the Earth's environment. We have entered the Anthropocene, an age where the actions by humans have, for better or for worse, an increasing influence on Earth and its systems.

There is a renewed attention to global environmental challenges, and understanding Earth Science is essential to thinking about those challenges, as well as potential solutions. Innovative Earth Science materials that encourage students to explore Earth Science concepts and the role of human activity upon the Earth are urgently needed. This article describes the High-Adventure Science: Earth Systems and Sustainability (HAS:ESS)(http://concord.org/projects/high-adventure-science) curriculum in which middle and high school students use computational models, analyze real-world data, and engage in building scientific reasoning and argumentation skills to learn about Earth Science and the effect of humans on Earth's systems. The National Science Foundation (NSF) has funded the development of five HAS:ESS modules. Two have already been developed; one exploring fresh water availability and the other exploring climate change (NSF Grant DRL-0929774). Three additional modules, in development, will explore the future of energy resources, land use and sustainability, and air pollution management (NSF Grant DRL-1220756) These web-based modules are available at no expense to teachers and schools.

The Role of Earth Science in Understanding Environmental Issues

Scientists in the Earth Sciences study dynamic Earth processes that have occurred throughout geologic time. Their research provides information on the frequencies, rates, and magnitudes of Earth system changes. These data provide a geological and historical perspective against which anthropogenic impacts can be evaluated (AGI, 1995).

Humans' use of Earth's resources, including soil, water, minerals, and energy, underlie many environmental issues. While Earth may have a certain resiliency allowing it to adapt to anthropogenic impacts, it is nonetheless clear that Earth's systems are changing under the pressures exerted by humans. Therefore, it is important to understand fundamental Earth science concepts as a foundation for analyzing human impact on Earth's systems.

A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas aims to foster student thinking about the interaction of Earth's surface processes and human activities. According to the *Framework*, "... humans have become one of the most significant agents of change in the near-surface earth's systems." (NRC, 2012) The High-Adventure Science curriculum uses framing questions about environmental issues as a way to help students focus on the core concepts of Earth Science while grappling with real-world issues.

Framing questions

The framing questions include:

- Will there be enough fresh water to sustain growing populations?
- How will climate change over the next 50 years?
- Is hydraulic fracking for natural gas the answer to our energy needs?

Each module includes interactive computational models that simulate Earth's complex systems, as well as data and evidence that scientists have collected. The modules challenge students to think critically about the framing environmental questions. The curriculum does not advocate a particular position, but rather encourages students to use relevant evidence to understand the role of human actions on Earth's systems.

Computational Models

Computational models are ideal for exploring geosciences and the impact of humans on the Earth. Our models simulate the evolution of a system and are based on mathematical algorithms that approximate fundamental physical laws. Much as scientists do, students can experiment with models by controlling the parameters, the starting conditions, and the conditions during a simulation. The models have vivid graphics and run quickly, so students can experiment and gain insights about the system by carefully observing the evolution of the system. Students can learn both the content and the process of science by experimenting with the models, and they can see the cause

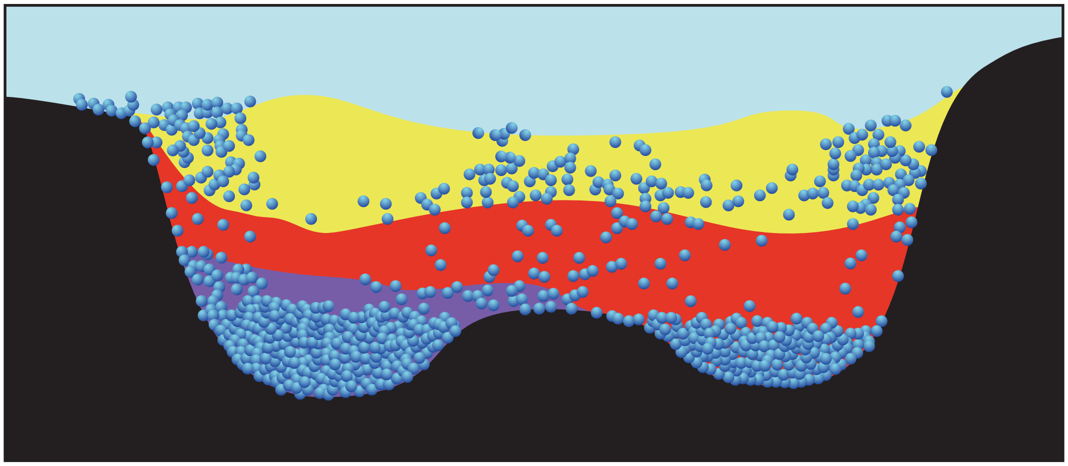

Figure 1. A computational model simulates the flow of groundwater. The colored layers represent layers with different properties. Blue dots represent water.

Source: By Author

and effect in a system because the behavior of these models emerges from science-based rules. Students can make predictions, and over many runs of the simulation, evaluate the validity of their predictions, thereby exploring the issues of uncertainty that are always inherent when predicting the future.

Every High-Adventure Science module includes a set of increasingly complex computational models that represent a particular Earth system (Figure 1). The models in the water module, for example, allow students to create different cross-sections through Earth's surface, saturate layers with water, place wells, change surface layers, change precipitation rate, and explore the outcomes of each change.

Will there be enough fresh water? An example curriculum

In the module entitled "*Will there be enough fresh water?*" (http://has.portal.concord.org/), students explore the relationship between freshwater usage and human population. Students use ground water models to discover how water flows above, through, and beneath Earth's surface. Students analyze water usage to propose solutions that may preserve clean, fresh water sources for the future. The module is designed for five 50-minute sessions, which can be done in class, as homework, or a combination of both.

The first activity, *Water in the world*, sets the stage. Students are introduced to the question about the future of Earth's supply of fresh water. Students explore the water cycle using a simple model and are asked to evaluate the supply and demand for fresh water in various areas in the world.

In the second activity, *How much water?,* Students evaluate their own personal water usage. Students then watch a video interview, embedded in the module, with a hydrogeologist who discusses water sustainability issues around the world.

In the third activity, *How does ground water move?* students use models to explore how water moves through substances of different permeability and porosity. Students learn how aquifers are created and begin to predict where water will be found in a given topography.

In the fourth activity, *Can we keep water flowing?,* students explore the movement of water in and out of the ground, via surface water bodies, including streams and ponds, and they analyze a case study of the Santa Cruz River in Tucson, Arizona.

During the fifth activity, *Using water sustainably,* students focus on the relationship between aquifer recharge and the rate at which water is pumped out for human use. In particular, students are introduced to a couple of ways in which humans have disrupted the water cycle and removed water from a system. Students compare the effects on aquifers caused by pumping ground water from urban and rural areas. Finally, students suggest solutions to a fresh water availability problem.

Assessing Student Understanding

Making and defending claims based on evidence is important to critical thinking, especially when teaching and learning about questions for which there are no definitive answers, as is often the case with Earth Science. To engage students in thinking about the unfinished science, the curriculum includes explanation-certainty item sets consisting of four questions that require students to 1) make scientific claims; 2) explain their claims based on evidence; 3) express their levels of certainty; and 4) describe the sources of certainty.

Students don't naturally justify their claims or reason about their certainty (Kelly and Takao 2002; Sandoval 2003), but our item sets encourage them to do just that. Helping students to interpret data, models, and experimental results, the High-Adventure Science curriculum attempts to bring frontier science and environmental issues into the classroom.

As an example, in the water module, students use models to explore where water pumps should be placed around a gaining stream (gains water from the groundwater table) to ensure a good flow (in

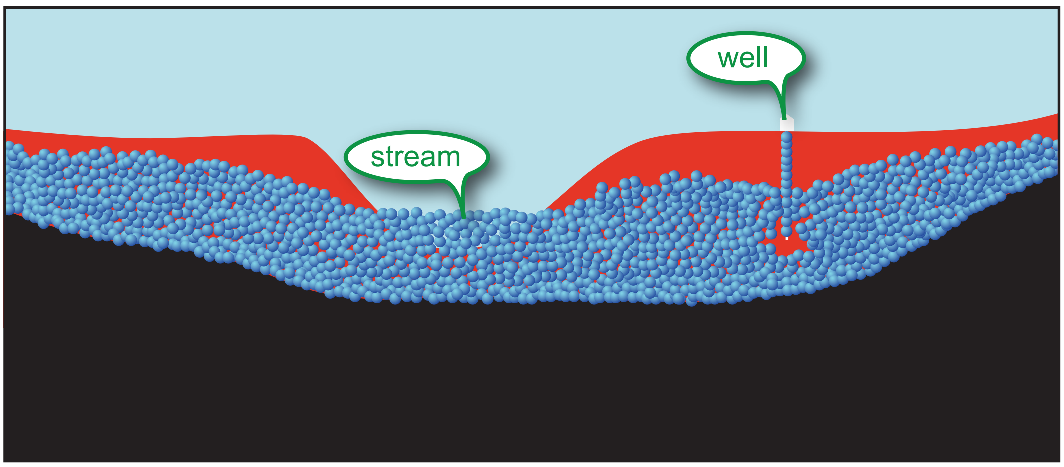

Figure 2. The following is an example of an explanation-certainty item set to be answered after experimenting with the simulation.
Claim: Where should pumps be placed around a gaining stream to ensure a good flow of water from the wells?
Explanation: [Explain your answer.]
Certainty rating: How certain are you about your claim based on your explanation?
(1) Not very certain, (2), (3), (4), (5) Very Certain
Certainty rationale: [Explain what influenced your certainty rating.]
Source: By Author

both the well and the stream). In the explanation-certainty item set, students decide where the wells should be placed, explain their choice based on their experimentation with the model, and express their certainty levels and rationales (Figure 2).

The item sets get more complex throughout the module and encourage students to reflect on the evidence (from both models and real-world data) and evaluate how certain they are about their scientific claims.

Effectiveness for Student Learning

Research was conducted on the effectiveness of the water module using pre- and post-test data. Analysis was done on the four-part explanation-certainty item, sets for 409 students from nine teachers. Results showed that students, after using the "Will there be enough fresh water?" curriculum, significantly improved their science content knowledge in all areas measured, as well as their scientific argumentation abilities (Pallant and Lee, 2012). Similar results were found for the climate change module.

Summary

The High-Adventure Science: Earth's Systems and Sustainability modules are designed to help students develop a deeper understanding of Earth Science concepts and how they relate to current environmental issues. It is critical that students know how Earth's systems interact to be able to fully explore the complex issues that society will confront in the face of anthropogenically-induced environmental changes. The High-Adventure Science curriculum has been shown to be effective in helping students develop an understanding of Earth as a system in the context of human pressures on these systems.

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About the Author

Amy Pallant is the Principal Investigator at The Concord Consortium where she is currently leading the NSF-funded *High-Adventure Science: Earth Systems and Sustainability (HAS:ESS)* project. On this project, the Concord Consortium is working with the National Geographic Society and the University of California, Santa Cruz. The goal of HAS:ESS is to enable students to understand real-world issues and help them makes sense of human-effects on Earth's systems. Ms Pallant has been developing curricula and contributing to research studies at The Concord Consortium for 12 years. Her work has been focused on the use of computational models to help students engage in scientific reasoning and argumentation. Ms Pallant can be reached at apallant@concord.org