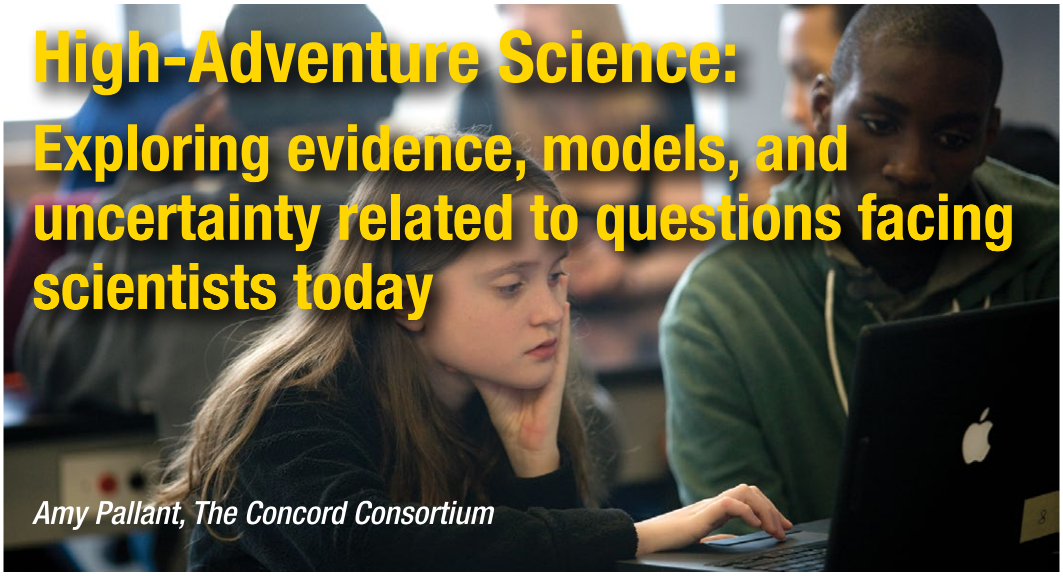

High-Adventure Science:
Exploring evidence, models, and uncertainty related to questions facing scientists today

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Abstract

This article describes the collection of free online High-Adventure Science curriculum modules and provides a detailed description of one of the modules (has.concord.org). With funding from the National Science Foundation, the Concord Consortium, in partnership with the National Geographic Society (NGS) and Technical Education Research Centers (TERC), developed modules that focus on contemporary questions related to climate change, freshwater availability, the search for life in space, land management, air quality, and energy choices. Designed for middle and high school students, the modules include real-world data, computer-based dynamic, interactive Earth system models, and scaffolded prompts to help students develop scientific arguments based on evidence and system dynamics thinking.

Introduction

> *Science's greatest advances occur on the frontiers,*
> *at the interface between ignorance and knowledge,*
> *where the most profound questions are posed.*
>
> (Siegfried, 2005)

There is something refreshing about encouraging students to explore frontier topics in their science classes. Students get the opportunity to engage with contemporary science and important unanswered questions that scientists around the world are still actively researching. Today, it seems that most of science education is a race to cover as many facts and concepts as possible. For students this can be dull and discouraging. Studies have shown that many students tune out of science not because they cannot master it, but because they don't see why or how science is relevant to their personal goals (Sjøberg & Schreiner, 2005). The emphasis on covering content also gives students the misconception that science is about what is known. They are exposed neither to the "high adventure" of science (Thomas, 1981)—what is unknown, which is what motivates many scientists—nor to how the field of science progresses.

The use of authentic contexts is a powerful way to increase student motivation, engagement, and learning (Chinn & Hmelo-Silver, 2002; National Research Council, 1996). However, authentic

The High-Adventure Science modules and other resources can be found online at http://has.concord.org/. To register for a free teacher account that provides access to pre- and post-tests, teacher guides, and a class management and student reporting system, go to https://has.portal.concord.org/.

science is not always accessible to secondary students or is not linked to learning goals, in part because these topics involve uncertainty (Lee & Butler, 2003).

The High-Adventure Science project has identified several important topics that are of great research interest, comprehensible to the target students, and linked to grade-appropriate learning goals. For each topic, we developed computer-based models to simulate the evolution of a system and allow students to change variables in the models. The models' vivid graphics make them compelling and they run quickly so students can observe how changes affect the system with each variable they modify.

The Next Generation Science Standards identify scientific argumentation skills as a key science and engineering practice (NGSS Lead States, 2013). Our four-part argumentation task is based on the well-known claim, evidence, reasoning (CER) framework (McNeill & Krajcik, 2007), with the added feature of asking students to elaborate on uncertainty, something that has been overlooked when exploring how students formulate arguments (Bricker & Bell, 2008). Based on Lee et al (2014) analysis of students uncertainty-infused argumentation tasks, we have determined that it is important to ask students to evaluate the strength of the data and knowledge in an argument and by doing so we have found that students who relate their claims to evidence are more likely to think about scientific factors when determining their levels of certainty (Pallant, Pryputniewicz & Lee, 2012).

Because High-Adventure Science module topics involve unknowns and models have inherent limitations, having students evaluate the uncertainty of the data they collected or are given as well as any and sources influencing the uncertainty are central to the curriculum. We developed a four-part scientific argumentation task to help students approach the complexity of the scientific arguments. The task prompts students to:

1. Make a claim
2. Explain their claim based on the evidence
3. Express their level of certainty with the claim and evidence
4. Describe their sources of certainty

Multiple argumentation tasks are embedded within each High-Adventure Science module to give students practice with making scientific arguments.

In our research studies to date, 53 field test teachers have used High-Adventure Science modules with over 4,500 students. Many additional teachers across a wide range of grade levels—from middle school to introductory university courses—have registered for a free teacher account at the project portal and used High-Adventure Science materials with their classes. Our work has contributed to the scientific education research field on argumentation by addressing how students incorporate uncertainty in formulating scientific arguments (Buck, Lee & Flores, 2014; Pallant & Lee, 2015) and describing how to assess uncertainty-infused scientific argumentation (Lee et al., 2014). We developed a methodology for promoting scientific argumentation using climate-based dynamic computational models (Pallant & Lee, 2015) and describe implications of using stocks and flows as a way to help students explore sustainability when using Earth systems models in a land management system (Pallant & Lee, 2017). Our research showed that student content understanding and argumentation skills improved when evaluating energy resources (Pallant, Pryputniewicz & Lee, 2017), climate change (Pallant, Lee & Pryputniewicz, 2013), the search for life in space (Pallant & Lee, 2015)(Pallant, Damelin & Pryputniewicz, 2013) and issues of freshwater availability (Pallant, Pryputniewicz & Lee, 2012) Analysis of students pre- and post-tests show significant gains in their understanding of both science content and scientific argumentation ability. Student argumentation abilities improved as measured by pre- to posttest gains ($p < .001$) by effect sizes ranging from 0.35 standard deviation for the "What are our choices for the future of energy?" module to 0.54 for the "Will the air be clean enough to breathe?" module.

The High-Adventure Science Curricula

The High-Adventure Science strategy is to use real-world data and computational models to drive student learning. Each of the six modules (see Table 1) is designed to fit into five 45-minute class

Table 1
High-Adventure Science Curricula Module Descriptions

Module	Description
Will the air be clean enough to breathe? (https://authoring.concord.org/sequences/389)	Students explore the interactions of factors that affect a region's air quality..
What is the future of Earth's climate? (https://authoring.concord.org/sequences/388)	Students learn about how increased greenhouse gas emissions affect some positive and negative feedback loops in Earth's climate system.
Will there be enough fresh water? (http://authoring.concord.org/sequences/98)	Students explore the relationships between rock porosity and permeability, rainfall, and some human actions on groundwater flow and the freshwater supply.
Is there life in space? (http://authoring.concord.org/sequences/390)	Students investigate how scientists find planets via the Doppler and transit methods and explore ways factors that are related to planet habitability.
Can we feed the growing population? (http://authoring.concord.org/sequences/385)	This module explores whether we can use existing farmland to produce enough food for a growing population while simultaneously protecting natural habitats
Will the air be clean enough to breathe? (https://authoring.concord.org/sequences/389)	Students consider whether we can keep air quality high while also producing energy. Students explore the relationships between pollution sources, geography, weather, and air quality
What are our choices for supplying energy for the future? (https://authoring.concord.org/sequences/386)	Students consider costs and benefits of different energy sources for generating electricity. Special emphasis is given to natural gas extracted from shale formations through the hydraulic fracturing process.

periods. Because interpreting data and dynamic models are complex activities, we break down the material into manageable pieces, providing scaffolding to interpret the evidence from each.

Each module and associated assessments went through several cycles of design-based research. Teachers were recruited to implement the modules and assessments in classrooms. Each teacher attended a two-day professional development workshop prior to implementation. All student work and responses to demographic surveys were collected electronically. Teachers gave feedback after each implementation. The modules and models were revised and the cycle repeated with more teachers.

The air quality module: Will the air be clean enough to breathe?

Here we provide an in-depth description of one High-Adventure Science module – "Will the air be clean enough to breathe?"– in order to highlight the learning progression. In this module students consider whether we can keep air quality high while also producing energy. They use models and real-world data to explore relationships between pollution sources, geography, weather, and air quality (Figure 1).

In Activity 1, students learn how to make a good scientific argument in the context of air quality science, and complete the first argumentation task structure of claim, explanation, uncertainty

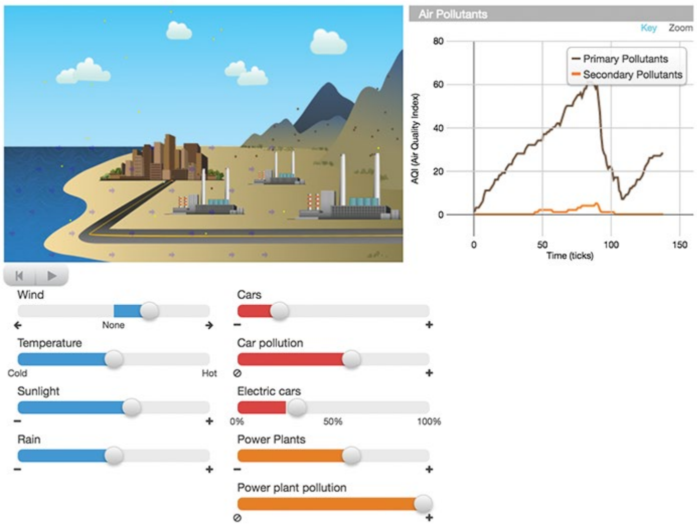

Figure 1. Screen capture of the "Will the air be clean enough to breathe" module.

ratings, and uncertainty attribute described above. In Activity 2 students explore the air quality index and a variety of factors that contribute to poor air quality (e.g., factory emissions or forest fires). They analyze data about increasing populations and consider how increasing populations impacts air quality. In Activity 3, students are introduced to computer-based dynamic Earth systems models. They use the models to explore how pollutants move throughout the atmosphere and consider the way emissions, chemical reactions in the atmosphere, transport of the pollutants, and deposition of the pollutants affect levels. Through experimentation with the models, including changing variables for wind direction and amount of pollutants, students discover the connection between how weather and geography are related to pollution levels over a city bounded by an ocean on one side and mountains on another (similar to Los Angeles). Students then explore another model that allows them to adjust environmental variables (wind, sunlight, and rain) to investigate each variable's impact on the severity of pollution. Students develop scientific arguments focused on the location of power plants and their influence on air quality in neighboring cities. Activity 4 introduces students to different types of air pollutants, including particulates and gaseous pollutants such as sulfur dioxide, nitrogen oxides, and volatile organic compounds. They consider the effects of the different pollutants on the health of humans and the environment. Students use models in Activity 5 to explore how primary pollutants interact with environmental components to form secondary pollutants. They also interpret real-world data related to ozone trends and acid rain. Finally, in Activity 6, they use models to investigate how atmospheric structure and conditions affect the severity of a pollution event by modeling thermal inversions. Lastly, students use a model to examine the impact of pollution control devices on the level of pollutants found over a city. They consider how individual actions might be able reduce the frequency of poor air quality events and develop a scientific argument to support their claims.

We analyzed pre- and post-test responses to claim, explanation, certainty rating, and certainty attribution items for 100 students. We found that after using this module, students significantly improved their argumentation abilities with a pre- posttest gain of 0.54 standard deviation, $p < .001$.

Teacher Response

Teachers who have used the High-Adventure Science curricula have underscored that students learn best when they themselves are familiar with the materials. "Teachers should be encouraged to examine the content of the modules prior to using the modules in their classes. While it might be tempting to think, 'I don't need to do that, the modules stand alone,' student questions can't be answered if you don't know about the situation that is being presented." Teachers' perceptions of student learning as analyzed from their feedback suggests that there was a steady improvement in student learning with models and graphs as they moved through the High-Adventure Science activities. Teachers indicated that High-Adventure Science experiences *enhanced* their lessons, with an average rating of 6.1 on a scale from 1 to 7 (with 1 indicating detracted from to 7 indicating enhanced) with 5 as the lowest rating. One teacher wrote, "My favorite features of your curriculum were the simulations. Almost every day I think about the particulates released by cars and power plants into the air because the simulation brought the concepts to life! I never run by freeways anymore. So thank you for changing my life and the lives of my students."

Conclusion

Science classes should engage students in "doing science" as scientists do science. Students should see science as an ongoing process rather than as a collection of facts. Compelling, cutting-edge research topics can help, but using them in the classroom is not easy as cutting-edge science has many unknowns.

The High-Adventure Science curricula provide an opportunity to bring contemporary science and the process of doing science into the classroom. Interactive, dynamic models help students make sense of complex Earth systems. Embedded assessments prompt students to interpret data from scientists and from models to make scientific arguments and evaluate claims—scientists' and their own—while considering the uncertainty inherent in frontier science.

The six High-Adventure Science modules are research tested and freely available. Module-specific pre- and post-tests, teacher guides, and answer keys are available with a free teacher registration at the High-Adventure Science portal.

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