Using SCIENTIFIC ARGUMENTATION to Understand HUMAN IMPACT on the EARTH

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Constructing scientific arguments is an important skill, and is specifically addressed by the *Next Generation Science Standards* (*NGSS*) science and engineering practice of Engaging in Arguments From Evidence. To ensure that students understand the significance of a scientific argument, they need experiences that will help them understand, use, and interpret scientific explanations, evaluate evidence, and think about the development of scientific knowledge. This article focuses on how I have used High-Adventure Science (HAS) modules (see "On the web") as a valuable tool for helping my 11th grade Earth science students consider scientific evidence as they develop critical-thinking and scientific-argumentation skills.

What is High-Adventure Science?

High-Adventure Science, developed by the Concord Consortium, is a series of free online modules designed for middle and high school students with a focus on human impact on Earth's systems. Each module has six activities designed to take approximately six 45-minute class periods, and can be previewed before assigning. The unifying theme is the exploration of frontier science—areas of study where scientists are actively engaged in research.

Each lesson consists of five multi-page activities and embedded assessments that guide students to unpack big unanswered questions such as, "What is the future of Earth's climate?" and "What are our energy choices?" Every lesson includes interactive, computer-based models and real-world data. Embedded tools help students develop scientific argumentation skills and evaluate their own reasoning by exploring evidence and analyzing issues of certainty—and uncertainty—while considering the limitations of the data.

Argumentation in the classroom

An examination of the *NGSS* grade-level progression for Engaging in Argument from Evidence (NGSS Lead States, 2013) shows that students in grades 6–8 should learn to construct written arguments using evidence and reasoning to support or refute an explanation or model. As students progress through high school, they should be able to evaluate claims, evidence, and reasoning to determine the merits of an argument.

When students hear "construct an argument" they often think in terms of an exchange of opposing viewpoints or an attempt to persuade others that an idea is correct or incorrect. Scientific arguments are different; developing a scientific argument involves defending a claim based on evidence, and should also include an examination of the evidence to determine its limitations and merits. My students often struggle with how to do this. I have also had difficulty in finding resources that provide robust contexts for these experiences.

Data representation in the HAS modules provides an authentic context for learning. Activities are interwoven through-

FIGURE 1

Students interpret real-world data of plant growth and make a claim.

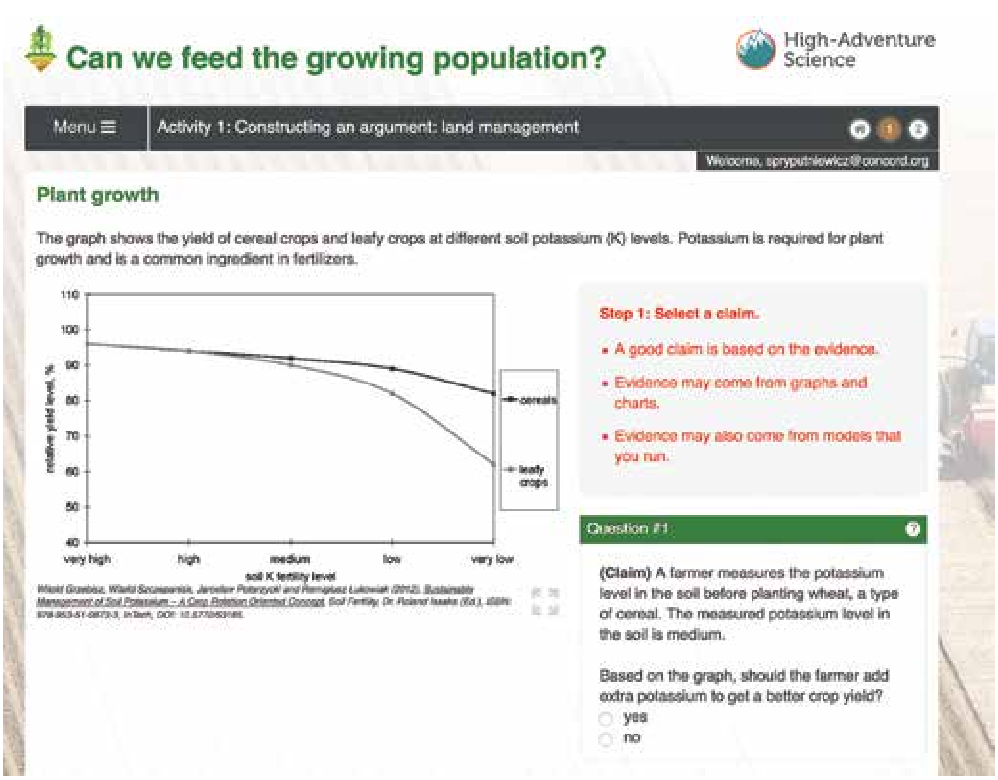


FIGURE 2

Example of scaffolding student thinking to support writing an explanation.

Step 2: Write an explanation.

- A good explanation will cite specific evidence that backs up the claim.
- When there is a graph or table, you can cite evidence directly from the source.
- When there is a model, you can describe what happened in the model.
- A good explanation combines evidence with scientific knowledge.

Question #2

Explain your claim.

Type answer here

This is an example of an explanation that correctly cites evidence from the graph.

The graph shows that the yield of cereals reaches its maximum at a very high soil potassium (K) level. However, the yield of cereals does not change much between very high, high, and medium soil potassium (K) levels. Therefore, the farmer does not have to add any additional potassium to get a good yield from the wheat crop.

FIGURE 3

Example of certainty rating items and scaffolding.

Step 3: Select a certainty rating.

- Picking a certainty rating is a way to signal how certain you are with your claim.
- Your certainty rating can be based on how well the scientific knowledge fits the evidence from models, charts, or graphs.
- Your certainty rating can also reflect on the quality of the evidence or investigation that produced the evidence.

Question #3

How certain are you about your claim based on your explanation?

Pick one

out the instructional unit so that as students examine the evidence presented in the modules, they are also busy collecting and interpreting their own data alongside other relevant labs and discussions. The HAS lessons challenge students to explore the relationship between using and interpreting models and model outputs and interpreting data as evidence to support a claim. There are prompts throughout the modules to help students develop scientific arguments.

Assessing and defending claims based on evidence is a key component of each activity. This is particularly important because students are dealing with topics for which there are often no definitive answers. The curriculum includes argumentation prompts asking students to

- make a scientific claim
- explain their claims based on evidence from models and/or data
- express their levels of certainty
- describe their sources of certainty

While my students have used the Claims-Evidence-Reasoning (CER) Framework (McNeill and Krajcik 2012) to help construct explanations, the idea of a certainty rating is new to them. My stu-

FIGURE 4

Example of scaffolding to support student evaluation of scientific certainty about claim and evidence.

Step 4: Write a certainty explanation.

- A good certainty explanation will explain why you are certain or uncertain about your response.
- Some topics are more certain than others. Consider the completeness of the evidence, biases in the evidence, and changes that could affect the trends over time.

Question #4

Explain what influenced your **certainty rating.**

Type answer here

This is an example of a certainty explanation that is based on the evidence.

I am pretty sure about my answer because the graph shows that the yield of cereals does not change much from high potassium level soil to medium potassium soil level. If the crop was a leafy crop instead of a cereal, there would be a more benefit from adding potassium. However, wheat is a cereal crop, so there is little benefit to adding potassium fertilizer.

dents initially want to rate their own correctness instead of focusing on the certainty of the evidence. This process provides the opportunity to discuss how to determine the reliability of data, how to identify authentic data sources, and enhances student reasoning skills.

Students explore land management through models

The module "Can we feed the growing population?" is particularly significant to my students, as we have seen a local shift in the number of acres used for agricultural purposes. The module lets students examine a variety of data and determine the relationships between land use and variables affecting the productivity of land.

We begin by discussing how land use is changing in our own area. Students also examine USDA land use data specific to our area (see "On the web"). Students share their observations in the classroom, allowing us to revisit them and compare them to data found within the module and collected in our own investigations. I use random numbers to group students into "talk partner" pairs. While the students submit individual responses, having a talk partner helps them learn how to reason with evidence (Michaels and O'Connor 2012).

In the first activity, students examine plant growth data. The CER framework (McNeill and Krajcik 2012) is embedded into the argumentation prompt in a clear and purposeful way. Students are asked to make a claim about the relationship between crop yield and soil potassium levels. I remind them that a good claim is based on evidence and then ask them to explain their claims. If they need help, I provide scaffolds describing the characteristics of a good explanation as well as an example (Figures 1 and 2). Students then rate how certain they are of the claim they have made based on the quality of the evidence provided, and write an explanation of their certainty rating. This allows the students to evaluate the merits of the evidence (Figures 3 and 4).

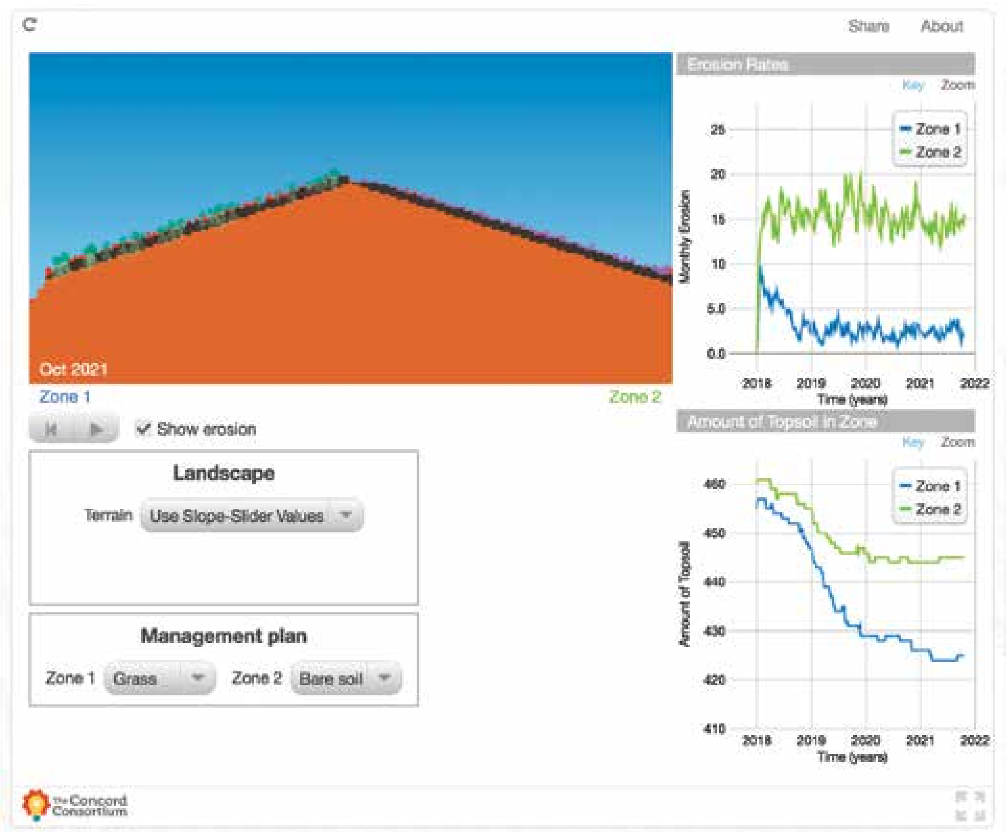
Student responses are collected in the HAS online portal, which allows me to examine individual student work and whole-class trends, and to provide feedback. Initially, many of them make an incorrect claim—the farmer should add more potassium in order to increase crop yield. Many students mention "maximizing yield" or "it doesn't harm anything if too much potassium is added."

Before continuing with the next HAS activity, students spend several class periods collecting and analyzing the physical and chemical properties of the soil from our campus, including testing the potassium level. Students use this data to make comparisons of their findings and the data in Activity 1. This pause from the module does not distract from the work; rather, it deepens the learning. The discussions surrounding both the activity and their data collection provide the students an opportunity to re-evaluate their initial arguments. They can revisit Activity 1 and make changes to their arguments as new learning occurs.

FIGURE 5

Example of erosion rates and topsoil amounts for different landscape slopes.

Students find that having plants (Zone 1) reduces the amount of erosion compared to a bare slope (Zone 2).



When we return to the module, students examine global land use and how land use has changed in the United States. The computer model allows students to explore what happens to different landscapes over a period of time as they change variables and compare outcomes from two different land management zones. To begin, students can change the slope of the landscape and whether plants are present in each zone. As the model runs, it generates real-time graphs of erosion rates and topsoil amounts (Figure 5).

It is interesting to listen to the students discuss manipulating the model and the changes they observe. They remind one another that both the model and the graphs are evidence that can be used in their arguments. Their arguments become more sophisticated and they become better at justifying why the evidence is important to their claim.

Embedded questions probe students' thinking and encourage them to examine scenarios which are realistic both to our local area as well as in other parts of the world. As they modify the computer model, they can see how the changes affect the soil and plant growth. The student pairs work to develop an explanation for how slope can affect a new housing development and the area surrounding it—a situation that is very real for them.

The module is an instructional tool and as such we do not work straight through it. Other relevant lessons are interspersed. An example of this is an activity on the impact of weather on our local agricultural production. Prior to the module activity focused on climate and plant growth, students examine local weather data to determine if there are any relationships between crop yield and weather conditions. In the HAS activity, students attempt to determine how precipitation affects soil erosion when there are different types of plants in each zone (Figures 6 and 7).

In addition to choosing landscape and management plans in the model, students can also vary precipitation amounts by changing climate variables. Students are asked to use evidence from the model to describe how soil erosion is affected by climate factors. At this point I ask students to compare their models with each other, with the goal of having this discussion guide the students' thinking as they develop their explanations.

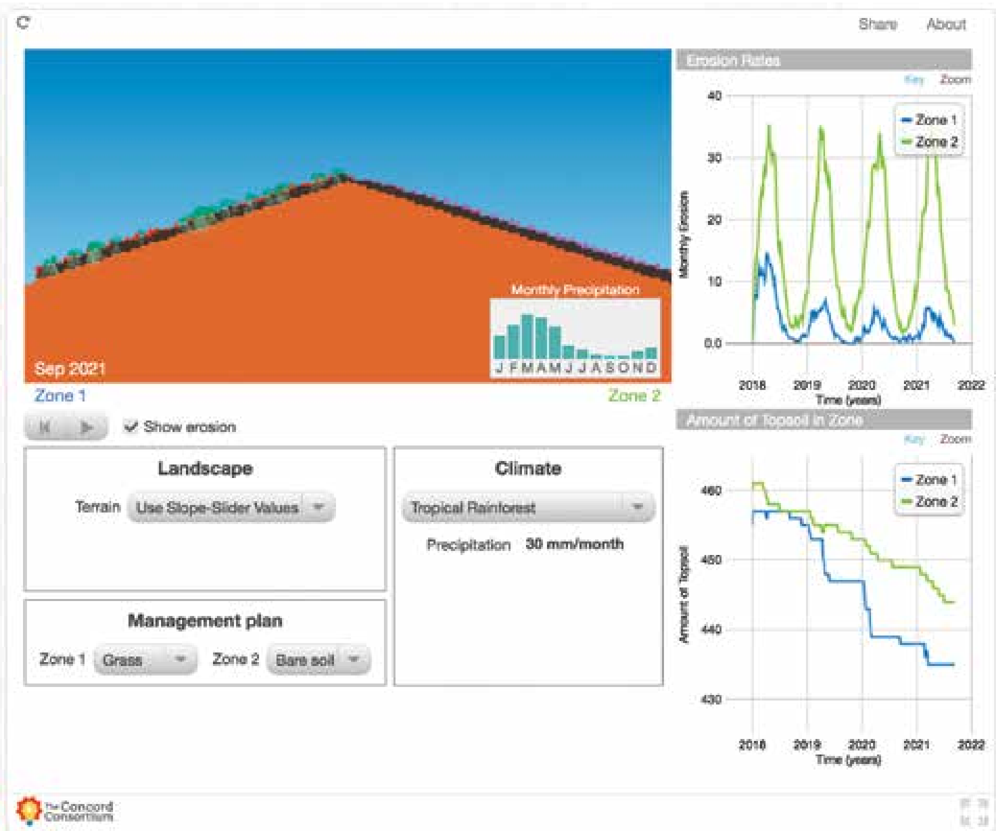
I use this as an opportunity to revisit the CER framework. We discuss what it means to use the evidence—how much is enough? Do the data support the claim? Students provide feedback on each other's explanations and make suggestions on how to make them better using the language in the scaffolds from the first activity.

The curriculum revisits the same model but introduces

FIGURE 6

Comparison of soil erosion in grassy areas and bare areas on a slope.

Students can see the periodicity of precipitation in the erosion rates.



new variables for students to explore as they progress through the curriculum. I have seen that this approach helps students understand the value of scientific modeling and the usefulness of the evidence these models generate. As the complexity of the models increases, students add to their understanding and examine their thinking. This becomes a powerful tool in helping students learn that scientists continually revisit their thinking, examine new evidence, and revise their models.

Student uncertainty in evidence and reasoning

After constructing an explanation, in this case related to the connection between wheat growth and precipitation, the students rate their certainty about their claim. The certainty ratings use a 1–5 Likert Scale with 1 being "Not at all certain" and 5 being "Very certain." After selecting the rating, the students must explain their reasoning.

This is a critical point in argument development. Explaining the certainty rating requires students to self-assess their thinking as well as evaluate the merits and limitations of the evidence used in developing their explanations. At first, students struggle with explaining their certainty ratings because it can be difficult to articulate the thinking behind their answer. I have found that a classroom discussion helps students move beyond self-evaluation and helps them think about the value of the evidence. Asking probing questions such as "How closely does the model represent the real world?" "What else should the model include?" and "How well does the model represent the relationship between wheat growth and precipitation?" helps them focus on the merits and limitations of the evidence from the models. It is during these discussions that I see my students realize that even though these questions are challenging, they can get better at considering the validity of evidence and how evidence is gathered.

Certainty ratings help students realize the flaws in their reasoning and serve as a tool for identifying "bad science." They enable students to evaluate limits and merits of what the models represent. The ratings also help students realize that there is a degree of uncertainty within any investigation and any phenomenon.

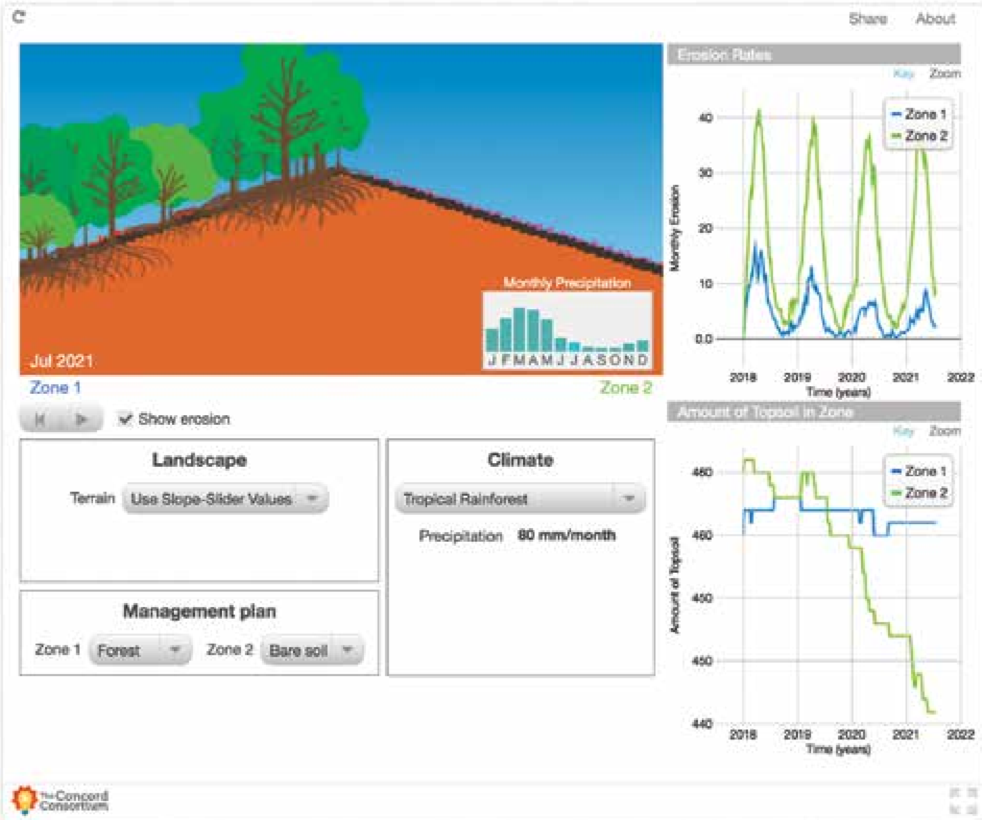
Assessment

Each module includes a pretest and posttest along with rubrics for student explanations and certainty rationales (see "On the web"). The pretest and activity responses are formative assessments that reveal prior knowledge and how students' thinking changes as they encounter new information. The posttest is the summative assessment and is given at the end of the mod-

FIGURE 7

Climate and Plant Growth

One student explained how precipitation affects soil erosion in forested areas compared to bare areas on a slope. The student stated, "As the amount of precipitation increases, the rate of erosion increases in areas where there is no plant growth. In the forested areas, the amount of topsoil remained basically the same."



ule. I am able to see and review all student work (from the module and the pre- and posttests) through an online teacher portal. Daily class discussions and reviewing student work in the teacher portal have enabled me to assess where the students are in their learning and to adjust my teaching to reflect the needs of my students as the unit progresses.

Student results

There are six HAS modules (see "On the web"). While the modules are designed to be used independent of each other, using several or all within a course helps build students' capacity to understand and develop scientific arguments. The modules also help students realize the significance of scientific modeling as they learn how models enable scientists to consider a variety of scenarios. One of my students commented, "Using the same modeling

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard

HS-ESS3 Human Sustainability

Performance Expectation

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.

HS-ESS3-3. Create a computational simulation to illustrate the relationships among the management of natural resources, the sustainability of human populations and biodiversity.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Using Mathematics and Computational Thinking Create a computational model or simulation of a phenomenon, designed device, process, or system.	Students run experiments with computational models to compare the effects of different agricultural land management strategies.
Disciplinary Core Idea	
ESS3.C: Human Impacts on Earth Systems The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.	Students explore the resources that make up our agricultural system and describe how humans maintain and replenish important resources to be able to produce food long into the future.
Crosscutting Concept	
Stability and Change Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.	Students explore how the extremes of precipitation affect plant growth. They use maps of average precipitation and temperature to predict which area will be best for agricultural production.

Connecting to the Nature of Science

Science Is a Human Endeavor Science is a result of human endeavors, imagination, and creativity.	Students explore the resources that make up our agricultural system and describe how humans maintain and replenish important resources to be able to produce food long into the future.

tool throughout the module helped me understand the relationships between different variables. It helped me to see the bigger picture and understand what is happening."

The role of student discussion is also important. At the end of each lesson, I provide time for students to ask questions and discuss their findings. By doing this I see students growing and learning about the role of collaboration in developing understanding, not unlike in the scientific community. Most importantly, these discussions help them see the relevance of the content to their lives.

In my class, as students shared their final thoughts on whether or not we can feed a growing worldwide population, other questions were raised:

- What happens to the land if different crops are grown each year? (Corn one year, soybeans the next year?)
- What happens to topsoil that is moved from the site of a subdivision or a new home site?
- What impact does fertilizer use and soil erosion have on our local water supply? Do these materials flow into the lake?

Examining pre- and posttest data also demonstrates students' deeper understanding of land management best prac-

tices. Their answers show a progression in their ability to use evidence to support their reasoning and their overall ability to construct scientific arguments.

Considerations for implemention

While the modules are designed as six 45-minute class periods, my pacing varies from class to class depending on the needs of the students. Teacher guides (including an overview of each activity), answer keys, and rubrics are available online once a teacher establishes an account on the Concord Consortium site. Supplemental materials are class-dependent. The activities include strong visual representations and are scaffolded in a way that is accessible to most learners, including students with IEPs and English language learners. The use of talk partners and discussion throughout the unit helps address most issues with different reading levels and making sense of the data and models.

Because each student creates an account on the HAS website, their answers are available throughout the module. Students always have the opportunity to review and edit their responses. I often review their work and provide feedback, which appears in the students' portal. This allows me to track individual student and class progress.

Conclusion

I have been teaching with the HAS modules for years. These modules made me think about how I approach teaching students about argumentation from evidence. Students need multiple experiences learning how to make sense of real data, using models to make predictions, and evaluating the merits and limitations of evidence. By embedding the various modules throughout my high school Earth Science course I have seen my students become more capable in constructing scientific arguments.

The *NGSS* practice of Engaging in Argument From Evidence is intended to help students understand how scientists think and work. It helps if they can learn about this while exploring experiences relevant to their lives. The HAS modules facilitate this process, and they serve as important tools for helping build student capacity in other science and engineering practices. The modules provide a platform for individual thinking, student–pair collaboration, and whole-class discussion—the types of behaviors and interactions that occur between scientists as they examine evidence and work together to develop explanations of various phenomena. I have also experienced the students' excitement as they discuss data and how the models can be used to simulate scenarios that are real to their lives. ■

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ON THE WEB

Rubrics for student explanations and certainty rationales: *www.nsta.org/highschool/connections.aspx*

USDA National Agricultural Statistics Service: *www.nass.usda.gov*

High-Adventure Science: *https://has.concord.org*

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