High-Adventure Science: Earth's System and Sustainability

Importance

Science's greatest advances occur on the frontiers, at the interface between ignorance and knowledge, where the most profound questions are posed [1].

If the 20th century was an expansive era, seemingly without boundaries, the early years of the 21st century have showed us the limits of our small world [2]. Over the last several decades there has been an increasing awareness of the ways humans impact Earth's systems. We have entered the Anthropocene, an age when the actions of seven billion humans have, for better or worse, increasing influence on the Earth. The most important example, it appears, is the permanent and global effects of burning fossil fuels [3].

There are, however, few places in school where students encounter material addressing human impact on Earth. Even basic geoscience courses have struggled to gain a presence in K-12 education [4], reaching fewer than 7% of U.S. high school students. Yet Earth and Space sciences (ESS) are a key component of science literacy as highlighted in "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas," hereafter referred to as "the Framework" [5]. Typical ESS courses underemphasize the role of human impact. Most textbooks relegate human interactions to sidebars except within chapters on Earth's resources and natural hazards, which are often ignored by students and teachers.

With renewed attention to human impact in related topics such as climate change and the need for alternatives to fossil fuels, innovative Earth science materials that encourage students to explore core Earth science concepts as well as the role of human activity upon the Earth are urgently needed. Teaching human-Earth interactions requires that students encounter core concepts such as the water cycle to understand fresh water distribution, the atmospheric greenhouse effect to understand climate change, and the rock cycle to understand fossil fuel and mineral resource distribution.

Students need contemporary science injected into their classrooms, engaging them in important unanswered questions that scientists around the world are actively exploring. Most of science teaching is a race to cover as many facts and concepts as possible. This can be baffling, deadly 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 science is relevant to their personal goals [6]. The emphasis on covering content also gives students the misconception that science is about what is known. They get no exposure to the "high adventure" of science [7], how science progresses, what is unknown, and what motivates scientists.

It is critical, in addition, that students develop skills that enable them to make sense of human effects on Earth's systems. They need to be able to explore scientific questions, assess scientific research, and draw and communicate conclusions to others [8]. In learning about human impact on Earth's systems especially, students need opportunities to undertake or evaluate scientific processes, such as making predictions, and consider the variability/uncertainty built into such predictions. Students must be able to project forward and consider likely scenarios; teachers must be prepared to consider the uncertainties inherent in making projections.

Goals and Objectives

The High-Adventure Science: Earth's System and Sustainability (HAS:ESS) project will develop modules for middle school and high school students in Earth and Space Science (ESS) classes, testing the hypothesis that students who use computational models, analyze real-world data, and engage in building scientific reasoning and argumentation skills will be better able to understand Earth science core ideas and how humans impact Earth's systems. The project goal is to research the effectiveness of the curriculum materials to reliably convey an understanding of Earth's systems and the increasing role of humans, while also introducing important science and engineering practices and crosscutting concepts.

The HAS:ESS project builds on Concord Consortium's (CC) promising NSF-funded exploratory High-Adventure Science (HAS) project, which demonstrated significant improvement in student understanding of frontier concepts in ESS and in scientific argumentation skills. Building on this prior work, the HAS:ESS project proposes additional targeted research in partnership with the University of California, Santa Cruz, a comprehensive treatment of human-Earth interactions, and a broad dissemination plan in partnership with the National Geographic Society.

Objective 1: Develop Curriculum Materials. The HAS:ESS project will create, research, and disseminate middle and high school curriculum that features computational models and covers five topics: climate change, fresh water availability, fossil fuel utilization, resource sustainability, and land use management. Two of these will be revisions of HAS modules and three will be new. Each module will take five class periods, use the HAS design of engagement with frontier science, and include a simplified computational model of similar models used in research.

Objective 2: Targeted Research. We will conduct three research studies. One will be a design study looking at how scaffolding built into the models, argumentation tools, and evaluation tools affects student understanding. The second study will be a quasi-experimental study to explore whether materials based on the design principles as modified by the first study are effective using a lag design. The third study will explore how student exposure to multiple modules contributes to student learning and attitudes about science.

Objective 3: Broad Dissemination. We will produce final polished materials ready to be promoted and distributed to a national audience through web resources at the National Geographic Society as well as through an HAS:ESS website hosted at CC, We will publish research results in peer-reviewed journals in science education and measurement journals. We will also present at conferences and disseminate curriculum and assessment materials through teacher networks.

PRIOR WORK

High-Adventure Science[1] (DRL-0929774. 9/15/09 – 8/31/12. $695,075. PI: Pallant). The HAS project is an exploratory DRK-12 project that brings the excitement of frontier science into the classroom by allowing students to explore pressing unanswered questions in ESS that scientists around the world are currently investigating. HAS consists of modules on climate change, fresh water availability, and the probability of finding life on other planets.[2] Each module is designed for five class periods and includes interactive computational models, real-world data, and a video of a scientist discussing his or her computer-based research on the same unanswered questions. To the best of our knowledge, no other project has combined all these principles to teach the core Earth science ideas related to human impact on Earth's systems whereas the HAS project addresses these concepts in two modules. More recently, several projects funded by NSF (such as Change Thinking for Global Science and Climate Literacy and Energy Awareness Network Pathway) have gathered and developed materials that help students explore the science and issues around climate change. These are excellent materials, but they are limited to climate change and do not include computational models.

HAS obtained impressive learning results. To measure learning gains, students were tested before and after the implementation of the climate change and fresh water modules using identical pre-tests and post-tests. The tests consisted of items that each had four parts: a claim, explanation, certainty rating, and certainty rationale. The explanations were scored using a Knowledge Integration rubric [9]. The uncertainty

[1] http://www.concord.org/projects/high-adventure-science

[2] The three modules and assessments can be viewed at http://has.portal.concord.org/investigations/list/preview

rationale rubric was developed using a phenomenographical approach where coding categories were generated to accommodate all student answers. In this effort, we initially identified 13 distinct categories that were further grouped into four higher categories: (0) no information, (1) personal, (2) scientific uncertainty based on the information in the module, and (3) scientific uncertainty based, in part, by science knowledge from other sources [10].

	No. of items	Maximum possible score	Pre-test Means (SD)	Post-test Means (SD)	Effect Size
(a) Climate Module (N= 137 students from three teachers)					
Claim	10	10	5.3 (2.1)	6.3 (2.2)	0.44 SD
Explanation	4	16	3.9 (1.6)	6.1 (2.1)	1.21 SD
Certainty rating	3	6	3.4 (1.7)	4.6 (1.5)	0.74 SD
Certainty rationale	3	9	2.4 (1.3)	2.9 (1.4)	0.36 SD
Total	20	41	15.1 (4.8)	19.9 (5.1)	0.97 SD
(b) Water Module (N=53 students from two teachers)					
Claim	9	9	5.2 (1.6)	6.9 (1.4)	1.13 SD
Explanation	3	12	5.1 (1.7)	7.0 (1.5)	1.20 SD
Certainty	3	6	4.2 (1.6)	5.4 (0.9)	0.91 SD
Certainty rationale	3	9	3.0 (1.9)	4.5 (1.9)	0.79 SD
Total	18	36	17.7 (4.6)	23.8 (3.4)	1.59 SD

Table 1. Summary of results. All gains have $p \leq 0.001$

The results in Table 1 were based on data collected as of December 2011.[3] Additional data will be collected and analyzed by June 2012. As shown in Table 1, students significantly improved in all four categories with $p \leq 0.001$. When combining all categories, students' improvement reached 1.59 SD for the water module and .97 SD for the climate module. These results indicate that the HAS curriculum design can support students' content acquisition as scored in the claim, scientific reasoning as shown in explanations that connect evidence to established knowledge or theory, and reasoning about the limitations of evidence as expressed in their certainty rationale.

Other projects. The proposed project also leverages the work of two earlier projects sketched below. The Principal Investigator was the researcher and curriculum developer on both projects.

Inquiring with Geoscience Data Sets (GEO-0507828. 8/15/05 – 10/31/07. $299,579. Co-PIs: Quellmalz and Zalles). The Center for Technology in Learning at SRI International and the Concord Consortium (CC) studied the impact on student learning of Web-based supplementary geoscience curriculum modules. The project developed two proof-of-concept units, one focused on data analysis along plate boundaries and the other on climate change issues. Findings indicated it was possible to (1) prompt a range of data analysis tasks, (2) provide end-of-module assessment tasks that measure near-transfer, (3) find evidence that the modules filled a gap in the typical secondary-level science education programs, and (4) determine that there were learning gains [11].

Making Thinking Visible: Promoting Students' Model-Building and Collaborative Discourse in WISE (REC-9980600. 1/152000 – 12/31/2002. $264,000. PI: Gobert, PI). In this project, a design study approach [12-13] was used to develop, test, and refine a curriculum for middle and high school students from the East and West Coasts to collaborate online about the plate tectonics in their respective locations.

[3] For additional detail on the research methods see the research report at http://concord.org/projects/high-adventure-science#cc1

Findings from this study showed substantial learning gains by students from diverse backgrounds of both content knowledge and epistemological understanding [13].

Research and Development Design

Curriculum Design Goals

Curriculum Goal. The goal of the curriculum is, in response to the Framework, to teach 1) science and engineering practices, 2) relevant crosscutting concepts, and 3) core Earth science concepts. The curriculum will be developed and tested iteratively in accordance with design research methodology [14-15]. We will test whether we can achieve the curriculum goal using five computer-based curriculum modules that incorporate a set of design principles stated below and further refine the design principles in later iterations on the basis of research [16].

Science and Engineering Practices using Model-based Experimentation. Because students will learn content by experimentation with computational models, the curriculum will scaffold them to undertake each of the science and engineering practices in the Framework, from "asking questions or defining problems" to "engaging in argument from evidence." To simplify the metacognitive load [17] the eight practices will be grouped into three phases of model-based experimentation [18]:

Planning. Students will record what they know and have learned, what general questions or problems require investigation, and what they learn from "messing around" with the model (practices 1 and 2).

Experimentation. Students will iteratively define a specific question that can be answered by a series of experiments with the model (practice 3).

Analysis. Students will summarize their experiments, develop their explanations, develop arguments from evidence, create diagrams, and communicate their understanding about the system under study (practices 4-8).

Crosscutting Concepts Related to Systems and Cause/Effect. All seven crosscutting concepts identified in the new Framework will be present in the curricula, but it would be a distraction to emphasize each. Because student learning in all five modules will be based on exploring models to identify causes and effects in systems with feedback, we will focus on two crosscutting concepts that match this instructional strategy: "Systems and system models" and "cause and effect." We explicitly identify these two concepts in the modules and we will design assessments that measure student learning of these themes.

Core Ideas. The five proposed modules address two of the three disciplinary core ideas in the Framework related to Earth and Space Science (ESS) and one in Engineering: "Earth's Systems," "Earth and Human Activity," and "Links among engineering, technology, science, and society."

Curriculum Design Principles

The following **design principles** will guide our curriculum.

Principle 1: Use open-ended, authentic, frontier science topics to frame the modules.

The Topics. The five modules will address the following current research topics:

1. When will fresh water resources become too scarce for human needs?
2. How will climate change over the next 50 years?
3. In what ways does land use impact the environment?
4. When will Earth run out of easily recoverable oil?
5. How might responsible management of electronic waste minimize environmental impact?

Justification. The use of contexts authentic to current practices is a powerful way to increase student motivation, engagement, and learning [19-20]. Authentic science is not always accessible to secondary students or able to be linked to learning goals at this level due to lack of students' knowledge and experience, as well as uncertainty involved in current science [21]. We have, however, been able to identify five modules that are topical and important, of great research interest, comprehensible to the target students, and linked to grade-appropriate learning goals. Together they cover the main topics in human-Earth interactions. In addition, we are able to develop educational computational models for each.

Principle 2: Acquaint students with working scientists, their research, and their use of computer models.

Connecting to science and scientists. HAS:ESS will continue the HAS approach to giving students opportunities to understand current research and the nature of science by multimedia introductions to scientists whose research involves computer models that are similar to, but vastly more complex than, the computational models used in the modules. This connection will be accomplished by resources from the vast collection of National Geographic Society's photos, videos, maps, and magazines on the current topics, and a blog of current science news related to the content of the modules.

Justification. By personalizing science, we combat the stereotypes of scientists by showing diverse scientists who work in teams and who can make an intellectual connection to students through their common use of computational models. By using social media, we tap into student familiarity with these tools and provide a way to keep the modules alive and current.

Principle 3: Use model-based experimentation as the primary means for students to acquire content.

The Models. Following the HAS design, every module in HAS:ESS will include a set of increasingly complex computational models that represent the system under study. The models in the "When will fresh water resources become too scarce for human needs?" module, for example, will 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. Student learning will be based on guided experimentation with the models. See Figure 1.

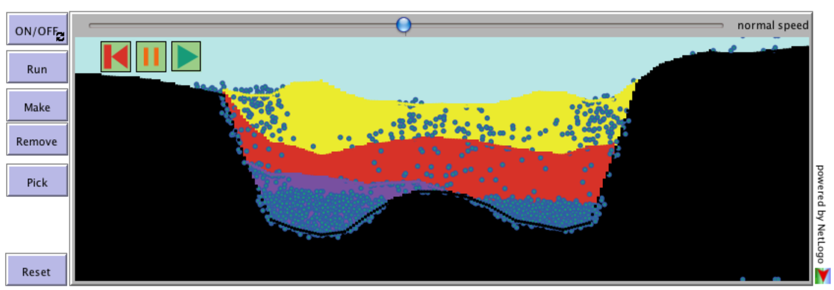


Figure 1. A computations model the represents groundwater flow. Each color represents a different layer with different properties. The blue dots represent water.

Justification. Computational models are ideal for exploring geosciences and human impact. Our models simulate the evolution of a system and are based on mathematical algorithms that approximate fundamental physical laws [22]. Much as scientists do, students can experiment with models by controlling the parameters, the starting conditions, and conditions during a run. The models have vivid graphics and run quickly, so that students can experiment and gain insights about the system by carefully observing the evolution of the system. Students can learn the content and the process of science by experimenting with the models, they can gain insights about contemporary science and scientists in the activities, and they can see the cause and effect in a system because the behavior of these models emerge from basic science-based rules. They can make predictions and over many runs, evaluate the probability of their predictions, thereby exploring issues of uncertainty inherent in predicting the future.

A substantial body of research shows that computational models and simulations allow students to understand through exploration the behavior of systems that are difficult to understand by other means [23–26]. Virtual environments that students can actively explore with tools and models are valuable for both motivation and content acquisition [27]. It is also important that students take an active role in trying different parameters, arrangements, and initial conditions to run experiments and see the results of their selections [28–31].

Principle 4: Engage students in building simplified dynamic systems.

MySystem. *MySystem* is a software tool that will be unique in combining 1) support for drawing causal loop diagrams that are completely qualitative, 2) a semi-qualitative system dynamics engine, and 3) scaffolding. Students will use *MySystem* to create their own diagrams in each module. Users can develop and run simple dynamics systems in *MySystem* by specifying relationships between objects in the diagram using semi-qualitative descriptive rules such as "If the CO_2 level doubles, then escaping IR will be halved." Because *MySystem* diagrams will be based on lumped parameters and simple rules, its applicability is limited, but it has the virtue that students can create diagrams and observe general system relationships that are common across many systems, such as equilibrium, feedback, oscillation, exponential growth and decay, accumulation, and rates of change.

Justification. Creating, discussing, and revising causal loop diagrams has long been shown to be an effective way for students to understand the behavior of systems with interacting parts [32–34]. Applications of system dynamics tools to precollege education have had many setbacks, largely because mathematical rules are difficult for novices to create. This has led researchers to create systems that rely on qualitative rules, notably *Model-It*, which has been used successfully with secondary students [35]. Current research indicates that, with appropriate scaffolding, system dynamics model building can be a powerful learning environment [34]. *MySystem* will incorporate the best elements of causal loop diagramming software, qualitative system dynamics models, and current research on scaffolding. Because we will use it in all the modules it can contribute to student understanding of crosscutting concepts: systems and cause effect.

Principle 5: Support scientific reasoning and argumentation.

Supports. Several features of the module design will support scientific reasoning and argumentation. The planning-experimentation-analysis sequence described above will be built into modules as separate pages that will include metacognitive prompts to guide student thinking. Students will engage in argumentation using four-part item sets that include claims, explanations, certainty ratings, and certainty rationales. Activities using *MySystem* will also monitor student causal loop diagrams and provide scaffolding by noting missing or non-normative links.

Justification. Engaging students in scientific argumentation deepens science concept learning, altering student views of science, and supporting student decision-making [36–39]. Research on scientific argumentation has grown substantially in the last ten years [40]. One aspect that has been overlooked, however, is how students treat uncertainty in formulating their arguments [41]. Uncertainty can play two roles when students construct an argument. One type of uncertainty represents students' confidence in their own knowledge and ability [42]. The other type is inherent in scientific inquiry due to measurement errors, lack of conclusive theories or models, and limitations associated with current equipment and technologies. Because all the HAS:ESS topics involve using models to predict future outcomes, issues about the reliability of models and the kinds of conclusions that can be justified from the models make student understanding of uncertainty a central focus of the project. As argumentation is a central scientific practice in the discourse of science, student argumentation will give students insight into how scientists construct knowledge [5, 43-44].

PROJECT RESEARCH

Research Questions

The research questions for this project are:

- How can we best use scaffolding to support students' model-based experimentation, system diagramming, and scientific reasoning argumentation when learning about Earth's systems and human impacts on them?
- How and to what extent do students' learning gains using HAS:ESS modules compare to students not using HAS:ESS?
- Do HAS:ESS modules promote student science practices as well as understanding of Earth science core ideas and human impact on Earth systems?
- What type of uncertainty do students exhibit while working with data and models? And how does uncertainty involved in frontier science influence student learning?
- How and to what extent do students learn scientific reasoning and argumentation, system building, and model-based experimentation if exposed to more than one HAS:ESS module in class?
- How do the HAS:ESS modules affect student ideas about the nature of science and practice of science?

Research Instruments

HAS:ESS modules are designed to promote student learning in the following five dimensions.

- **System diagramming** focuses on students' ability to define the Earth system under study, specifying its boundaries and making explicit its interacting parts [45–48]. Students will be asked to predict system behaviors and explain causal relationships and the mechanisms by which they are related. We will be able to assess students understanding of crosscutting concepts using *MySystem* diagrams.

- **Scientific reasoning that represents student understanding.** Holyoak & Morrison [49] characterized reasoning as part of thinking that "places emphasis on the process of drawing inferences (conclusions) from some initial information (premises)." Scientific reasoning, therefore, refers to drawing inferences from initial information such as data or evidence based on scientific knowledge accepted by the community of scientists and can be measured in scientific explanations students provide [48-49]. To measure scientific reasoning that represents student understanding of the content, we will use the knowledge integration assessment framework that has been validated in multiple classroom-based trials for psychometric rigor [9], instructional sensitivity [50-52], technology-enhanced learning [48], and learning progression [50]. The knowledge integration assessment framework is based on knowledge integration theory [53], which portrays the developmental direction of scientific reasoning based on the number of scientifically normative and relevant ideas students elicit and the number of elaborated links among the elicited ideas [54].

- **Model-based experimentation** involves using a computational model to answer a given scientific question. In our curriculum context, model-based experimentation will consist of asking questions, planning and conducting investigations using models, analyzing and interpreting data from running the models, constructing explanations, and reflecting on limitations. We will examine students' experimentation strategies, the extent to which students attribute the effect to the cause, and scientific arguments they develop after running their models [53].

- **Scientific argumentation** will be measured on the extent to which students make reliable claims based on available evidence backed by accepted scientific knowledge or theory as well as the extent to which students recognize limitations associated with their claim and evidence-based justification. The item format and scoring methods have been developed for the HAS project[4]. Scientific argumentation items for two of the five planned HAS:ESS modules have been already vali-

[4] For examples of item format and scoring methods, see research report at http://www.concord.org/projects/high-adventure-science#cc1

dated. Scientific argumentation items for the new modules will be created and validated in Year 2 using the established method.

- **Image of Current Science** promoted in HAS:ESS concerns students' recognition of how scientists work, the uncertainty and tentative nature of scientific inquiry, and how scientific research is being communicated and debated. We will modify nature of science items available in the literature, such as Views of Nature of Science (VNOS) [54] and Views on Science-Technology-Society (VOSTS) [58] to fit the Earth science contexts.

Research in the HAS:ESS project will be conducted in three phases, described below.

Year 1: Design Studies within Classroom. Literature on model-based experimentation, building of system dynamic models, and scientific reasoning and argumentation indicates that students cannot effectively achieve scientific understanding and practices without proper support [59–61]. The design studies in Year 1 focus on the scaffolding we will incorporate in the HAS:ESS modules.

To support **model-based experimentation** on the complex Earth's systems, we will scaffold students' exploration of variables that can illustrate most salient results for understanding how Earth's systems in question work for a given scientific question. To support the development of **integrated understanding of complex Earth's systems**, we use the *MySystem* tool. To support **argumentation**, we use verbal scaffolds for claim, justification, and certainty considerations. In Year 1, we will test each of these three scaffolding features incrementally. We will conduct these design studies with the "How will climate change over the next 50 years?" and "When will fresh water resources become too scarce for human needs?" modules that were developed for the HAS project.

In the first design study, we will create one curriculum version with claim and justification scaffolds as control and the other with claim, justification, certainty, and certainty rationale scaffolds as the treatment. We have studied the scientific argument scaffolds format in HAS, but did not establish the instructional benefits associated with adding certainty and certainty rationale prompts to claim and justification scaffolds. In the second study, we will create two curriculum versions that differ in the way students explore the parameter space to test models. In the control version, students will see all objects that interact at the same time and will be able to control variables on their own. In the treatment version, students will be guided as to which particular constituent to follow and control over multiple trials. In the third study, the treatment version will include the *MySystem* tool. The control version will not have the *MySystem* tool. See Figure 2.

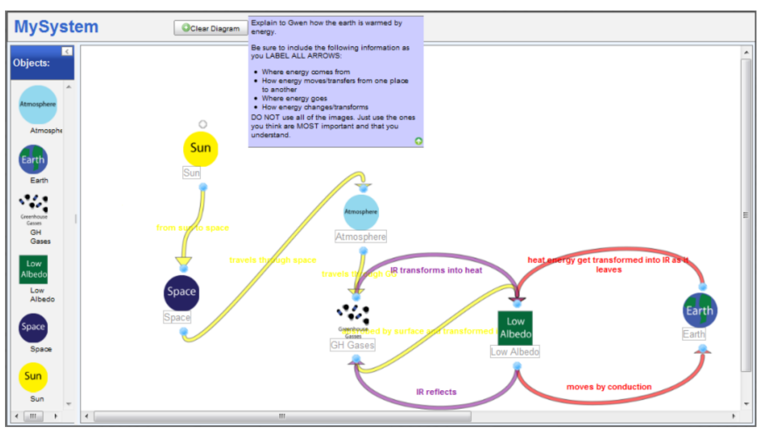


Figure 2: Systems diagram created in MySystem

Three teachers in the design study will participate from Framingham, MA, and the Bay Area, CA, local to the researcher at CC at UCSC. Each teacher will run two modules in two or more classes of approximately 25 students. Half of each teacher's students will be assigned to the treatment version of the module and half to the control version. We will schedule the studies so Teacher 1 will run the modules in October, Teacher 2 in January, and Teacher 3 in April. Project personnel will observe classes. After each design study, changes will be made to the modules to incorporate the best understanding of the design principles. For each design study, we will collect student demographic variables, student pre- and post-tests, all student responses to model runs, and arguments generated during the module. In particular, we will provide prompts within the curriculum to get students to describe their model experimentation strategies. The resulting design principles associated with argumentation, modeling, and system learning will be incorporated directly into the new modules that are being developed during Year 1.

Year 2: Formative Research. The research will focus on how the new curriculum materials that include the refined design principles work to improve student learning of Earth science core concepts, scientific reasoning and argumentation, and model-based experimentation. Additionally, new assessments for these student learning outcomes will be validated for the new modules using established procedures, such as inter-item reliability (Cronbach's alpha), construct modeling procedures [59–61], and Rasch modeling. The project research will use a lag design, as the HAS:ESS curriculum context on human interactions with Earth's systems is new to many existing Earth science curricula. The lag design will provide a control group and ensures that all students eventually use the materials. Six teachers all familiar with the HAS modules will pilot the modules in several of their classes, starting in the second year. Six additional teachers who match the pilot teachers based on school locale, socioeconomic status of the school, and relative academic standing measured by available public student performance records, will serve as a comparison group for that year. All 12 teachers will use the materials in the third project year.

The research design allows us to compare student gains with and without treatment in the same classrooms in different years (year 2 and year 3), reducing much of the variability from teacher and school environmental factors. For this study, the unit of analysis is the teacher. Gains between the two years in the control classrooms of year 2 can be also expected. The classes that use the HAS:ESS modules in both years will give an indication of the size of teachers' maturation of the HAS:ESS approach.

The teachers, though familiar with the HAS curriculum, will attend a two-day teacher professional development workshop at the Concord Consortium and be supported throughout the year with online mentoring and social networking. The six teachers, providing comparison classes, will attend an online workshop. We will collect student demographic information, student ideas about nature of current science, and pre- and post-tests for all students (in both pilot and comparison classes). To make assessment accessible to students who will not have experience with *MySystem* and the computational models used in HAS:ESS, items on system building and model-based experimentation will not require students' exhaustive engagement with the technologies. For example, we will use critiquing diagrams of Earth's systems and show results of several model runs to guess the relative importance of factors. Both control and treatment groups will take identical pre- and post-tests online. All of the student responses and artifacts generated from the HAS:ESS modules will be available for analysis. We will use repeated measures ANOVA to estimate the impact of modules on student learning outcomes in each teacher as well as across teachers. When comparing the impact of curriculum modules across teachers, we will also take into account how well the HAS:ESS modules are implemented based on data collected from the evaluator (see below) to control for fidelity of implementation.

Participating schools

We have recruited and received letters of support from nine teachers so far. The teachers come from schools that are located in Framingham, MA, Las Vegas, NV, Worden, MT, Waterville, NY, Brooklyn, NY, Salem, WI, Mooresville, IN and the Bay Area in CA (see Supplementary Documents). The teachers come from urban, suburban, and rural schools, and represent diverse classroom settings in terms of language and school type (public and private). These districts are geographically dispersed and diverse in terms of populations served, and represent both small and large schools. For example, the Framingham, MA, Public Schools serve a suburban population that is approximately 35% racial and ethnic minorities, where 27 % of the students receive free and reduced price meals. Waterville Jr. Sr. High School in Waterville, NY, on the other hand, is a small, rural school district where 36% of the high school students receive free or reduced-price meals. Lenox Academy for the Gifted in Brooklyn, NY, is an urban school that serves 99% minority students, with 70% receiving free and reduced price meals. With these districts we will be able to explore the implementation of the modules in a wide variety of settings.

Year 3: Summative Research. In the third year, all 12 teachers will attend a second two-day professional development workshop at CC. During the school year, they will implement a minimum of three of the modules consecutively, and we will explore students' Earth science content learning gain, and learning progressions in system building, scientific reasoning and argumentation, and model-based experimentation from module to module. This is important since science practices may not be mastered through short-duration exposure to an intensive intervention. We hypothesize that by repeated exposure, students will be able to more effectively learn complex Earth's systems, formulate scientific arguments, and conduct model-based experimentation. We will collect student data throughout the year with beginning of the year pre-test, pre- and post-tests around each module, and end of the year post-tests. We will follow students' argumentation, modeling, and causal loop diagramming at multiple points over the year to examine the extent to which students improve over time. In addition, we will utilize fidelity of implementation information data gathered by the external evaluator on the amounts of time students spent on the entire set of activities, each activity, and each task where the computational models are used. We will use a growth curve analysis on these individual learning trajectories.

PROPOSED MODULES

The following describes each of the HAS:ESS modules. Teacher guides for each module will align to the National Geographic Society's instructional model and will include an overview, learning goals, background resources, lesson plans, support for teaching each of the design principles, paying particular attention to methods necessary for dealing with model-based experimentation, uncertainty with data and models, and systems diagrams. In addition, the teacher guides will include suggested discussion questions and answers to all questions.

When will fresh water resources become too scarce for human needs? There are many unknowns affecting fresh water availability. For instance, freshwater is not distributed evenly around the globe, and human needs and changes in populations affect whether there is enough water for agricultural, industrial, and/or domestic use. Developed for High-Adventure Science, this module provides students with an Earth's systems model showing the movement of water through air, infiltrating the ground, pooling in various reservoirs, and being withdrawn for human purposes. We guide students to explore the rate of recharge and rate of withdrawal in different systems. For example, students explore human impact on groundwater availability by experimenting with the effects of urbanization, population increase, and climate. Students also explore core ideas of porosity, permeability, and landform. Adding to the HAS modules, and for each of the new modules developed in HAS:ESS, we will also explicitly have students define the Earth system and all its parts being modeled, experiment and make claims about the cause and effect of human interactions in each scenario, and diagram the system's inputs and outputs.

How will the climate change over the next 50 years? This module will introduce the fundamental science concepts needed to understand how changes in atmospheric greenhouse gases are related to changes in atmospheric temperatures. Students explore core concepts of how the ocean, ice, clouds, and atmospheric gases are major influences on climate. Originally developed in HAS, the computational model simulates complex interactions of these different variables. Students change inputs and compare model outcome to climate change data scientists have gathered. Students use the models to forecast future changes and investigate how changes may be affected by natural causes as well as by human activities.

In what ways does land use impact the environment? This new module will model how changes in land use for agriculture, urban and rural development, and deforestation impact world ecosystems. Students will explore concepts related to weathering, soils, and mass movement. With the model students will evaluate the risks and benefits of land use and explore human population distribution and how that affects the various land use needs.

When will Earth run out of easily recoverable oil? This new module will focus on learning about renewable and nonrenewable energy resources. Students will explore distribution of energy resources and describe the origin, occurrence, and use of various fossil fuels. The models will help students explore rate of resource extractions and resource availability as it relates to population demands.

How might responsible management of electronic waste minimize environmental impact? Taking a slightly different perspective, this new module will explore how rapid changes in technology, falling prices, and planned obsolescence have resulted in a surplus of e-waste. The models will help students investigate the relationship between resource management, mineral distribution and availability, production and reuse, and recycling efforts. Focused on sustainability, students will diagram different scenarios to explore the long-term impact sustainable practices might have on the environment.

Technology development

The project materials will be entirely computer-based and able to execute in any browser that supports HTML5, which means that they will be able to run all school computers and many tablets and other portable devices. The required technology includes the computational models for each module, the *MySystem* tool, and an authoring and delivery platform.

We prototype the computational models using NetLogo and then convert them to JavaScript. Each module will use several versions of a model, starting with a highly simplified one and gradually introducing more factors. The rapid prototyping possible in NetLogo facilitates experimentation with the design of the versions as well as the user controls, algorithms, and displays, and produces software suitable for classroom testing. NetLogo prototypes of groundwater and climate change models, each in several versions, were developed in the HAS project. Similar models will be developed for the three new modules. HAS:ESS will then convert all five NetLogo models into JavaScript. From the beginning of the project we will work with National Geographic Society to develop design standards so the models and modules will be ready for distribution on their website. Because we have more control over JavaScript, this process will result in faster and far more polished visualizations.

MySystem is an open source package developed by the Concord Consortium in JavaScript that currently allows users to create qualitative causal loop diagrams such as shown in Figure 1. It was designed to include qualitative system dynamics capacity similar to Model-It, but this has not yet been implemented. The HAS:ESS project will add this functionality.

As we use the term, a platform is used to present materials to students, handle user identification, provide assessment and teacher reports, and support authoring. All software developed at the Concord Consortium is open source, mostly released under the LGPL or similar license. This permits us to use appropriate open source code developed elsewhere, and to engage others in improving our code. In addition, it ensures that our code is and will remain free.

Dissemination

The project will create a rich legacy of materials, including online curriculum modules, teacher guides, and research. All curriculum materials will be available in electronic form on the National Geographic Society Education website. NGS will promote the materials to their digital audience through various channels: Facebook, Twitter, blogs, and newsletters. Once online, materials will be hosted on the National Geographic Education website and included as part of their curriculum materials library. The National Geographic Education website is a nationally recognized and valued resource visited by five million website visitors every year.

The Concord Consortium will produce an HAS:ESS project website, which will connect to the National Geographic Education website, and will include results from our research and evaluation. CC will also promote the materials through various digital channels, including Facebook, Twitter, blogs, and other social media. Additionally, all the partners will promote the project through presentations and workshops at conferences (NSTA, NECC, and NARST) and through articles published in peer-reviewed journals in science education and research, as well as in the *@Concord* biannual newsletter that is mailed free to 8,000 readers in print and an additional 1,500 electronically.

EVALUATION

The HAS:ESS evaluation will document the *development and research process* throughout the project and will *measure teacher implementation and student learning* during both the formative and summative testing. The evaluation will be led by Dr. Karen Mutch-Jones from the Evaluation Group at TERC, which focuses exclusively on STEM research and evaluation.

Supporting and documenting the development and research process: By providing external oversight throughout the project, the evaluation will support staff in tracking progress. The evaluators will collect descriptions and data about ongoing work from the design studies, meeting observations, and staff interviews. In collaboration with project staff, these data will be compared to the project's proposed goals, timelines, instrumentation, and research strategies so that ongoing activities and deadlines can be realigned with intended plans and/or intended plans can be adjusted to thoughtfully account for the realities of project work. Staff reflections and conceptual as well as management decisions will be documented to help staff monitor their responses to ongoing challenges, unanticipated outcomes, and achievements. This process will help to ensure evidence-based decision-making and validate project work. Finally, dissemination plans and efforts will be documented and discussed with staff so that both that HAS:ESS materials and research results are widely shared.

Formative Evaluation of Teacher Implementation. HAS:ESS participating teachers must effectively use the modules while integrating opportunities for students to apply and reflect on their new knowledge, scientific reasoning and argumentation skills, and model-based experimentation skills. Therefore, data collected about teacher implementation in Year 2 will provide formative feedback leading to the refinement of the modules, professional development, and decisions about ongoing supports related to specific needs. In addition, these data will provide the research team with a clearer picture of the range in HAS:ESS classroom implementations so they can hone their questions and instrumentation for measuring student outcomes. This aspect of the evaluation will be guided by the following questions:

1. To what extent and how does HAS:ESS professional development and ongoing project supports influence teachers' confidence, level of engagement, and ability to use the modules with fidelity?
2. How do teachers introduce and teach scientific reasoning and argumentation, causal loop diagramming, and modeling skills within the HAS:ESS modules?
3. What is challenging about instructing with HAS:ESS modules, and how do teachers respond to these instructional challenges?
4. How do teachers' backgrounds (Earth science knowledge, prior work with computational models, experience with argumentation) and classroom/school contexts impact fidelity of implementation, teachers' roles when instructing with HAS:ESS, and level of comfort?

Summative Evaluation of Teacher Implementation: For the field test in Year 3, we will conduct a summative evaluation in which we continue to ask questions 1-4 above, while also probing level and quality of teacher implementation to determine how it affects student learning outcomes. The following questions will guide this latter aspect of evaluation:

5. How does level of HAS:ESS module use (number of modules) influence teacher knowledge and practice?
6. To what extent and in what ways do teachers support and respond to student questions and uncertainties with HAS:ESS curricular components?

Instrumentation and Data Collection (for both Formative and Summative Phases): The following instruments will be tested in Year 2 and revised and extended for Year 3:

- Teacher pre- and post-implementation surveys will provide measures of teacher confidence and practice. The surveys will ask about the teacher's own knowledge gains, level of preparation to use

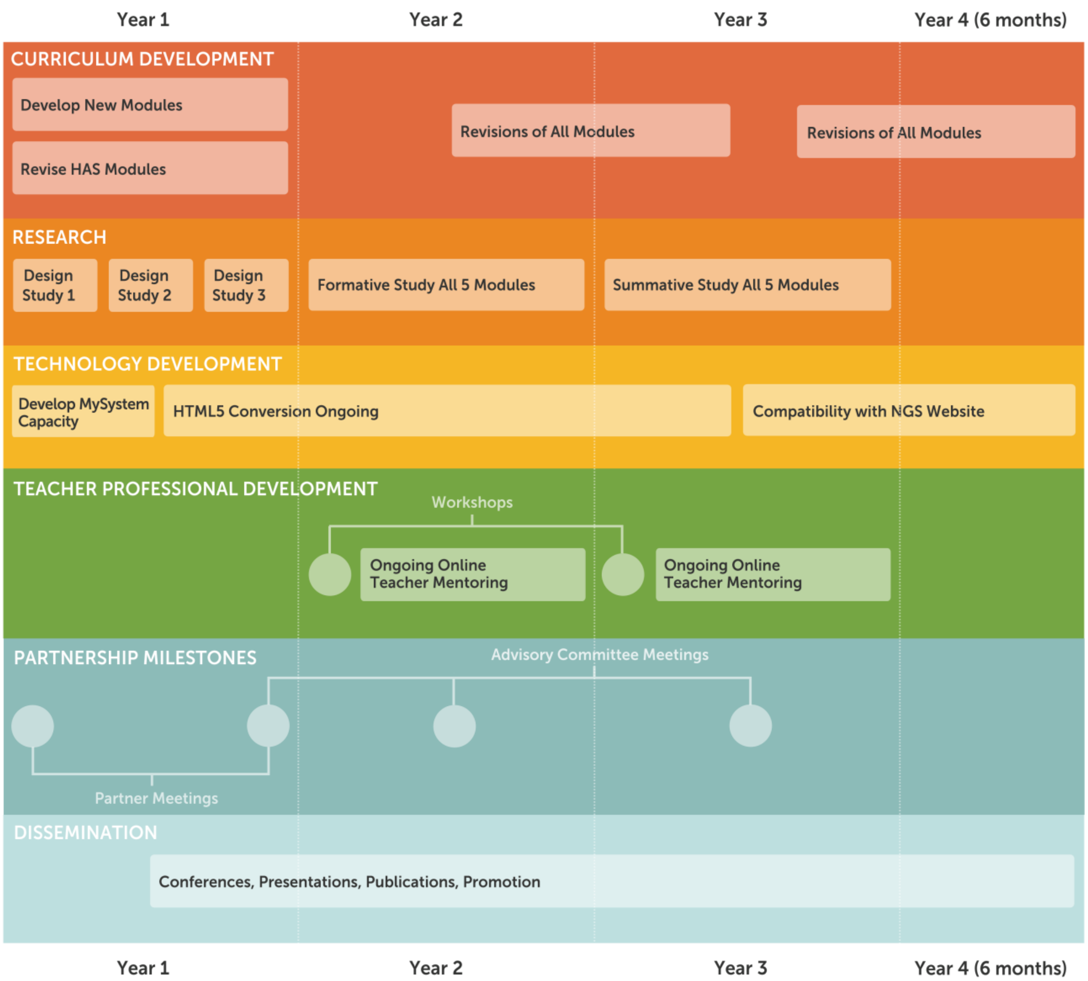
HAS:ESS, and continuing challenges and needs.

- Teacher logs will capture which components of the HAS:ESS curriculum are used during the entire implementation period. They will also ask teachers to identify sequence, extent, and ease of use, along with a description of any supplemental materials they may have used.
- Scored teacher assessment of student argumentation at baseline, following implementation of one HAS:ESS module, and following implementation of their last HAS:ESS module. These assessments are intended to measure change in teachers' ability to evaluate student reasoning to instructional responses, aligned with the HAS:ESS to student uncertainties.

Evaluators will examine correlations among indicators in this evaluation data set (e.g., extent of module use with ability to evaluate student reasoning). Associations and difference in scores will offer important information on teacher confidence and will be a first step in understanding how variation of an indicator might be related to other indicators. These findings will provide important information about the range of ways in which teachers use HAS:ESS tools and instruct within HAS:ESS units. In addition, quantifiable data about teacher characteristics will be shared with project researchers so they can create variables to account for the influence of teacher on student outcomes.

PROJECT SCHEDULE

This will be a three and a half year project beginning in July 2012. Activity development will begin immediately, as will the design studies research. The second year will focus on formative testing and revisions. Summative testing will occur in the third year. The final six months will be devoted to research publications and readying materials for broad dissemination via our partnership with the National Geographic Society.



EXPERTISE

KEY STAFF

Amy Pallant will serve as Principal Investigator. She will be responsible for overall coordination and budgeting of the project. She will direct the development of the curriculum materials, and coordinate the technology development, research and evaluation. She is currently the Principal Investigator for the High-Adventure Science project. She managed, wrote curriculum and conducted research for the other Earth science curriculum development and research efforts at CC. She has been the project manager, educational researcher, and curriculum developer on the award winning Molecular Workbench projects. Previously she developed science curriculum at EDC. Amy holds an M.A. in Science Education from Harvard and a B.A. in Geology from Oberlin College.

Dr. Hee-Sun Lee will serve as co-PI for the project. She will be responsible for management of the research design, data analysis, and managing the work of her graduate and undergraduate students. Dr. Lee is currently a Visiting Assistant Professor at the University of California, Santa Cruz. She specializes in curriculum and assessment material development and small- and large-scale evaluations of innovative curriculum materials. She directed a large-scale assessment research project at the NSF-funded Technology-Enhanced Learning in Science (TELS) Center where she developed the knowledge integration assessment framework. She earned an M.S. in Physics and a Ph.D. in Science Education from the University of Michigan. She completed a postdoctoral training at the University of California, Berkeley, at Dr. Marcia Linn's lab, and held an assistant professor position at Tufts University.

Patricia Norris will serve as co-PI for the project. She will manage staff at the National Geographic Society and provide expertise in media use, curriculum design, and design of materials for large audiences. She with staff at NGEP will identify images, video maps and other NG media to be included in the curriculum and prepare them for use. Ms Norris is director of Education Online at National Geographic Society. She has produced the Xpeditions Website for NGS. She holds an Ed. M from Harvard Graduate School of Education in Technology, Innovation & Education.

Dr. Robert Tinker will serve as Senior Science Advisor and will help create the prototype computational models for the curriculum and guide the development of *MySystem*. He founded the Concord Consortium and has overseen many successful projects in educational technology. He founded the Concord Consortium and has served on numerous boards and committees, including the National Academy of Science advisory committee that developed NSES and the President's Committee of Advisors on Science and Technology. He holds a Ph.D. in experimental low temperature physics from MIT.

Nathan Kimball will serve as curriculum developer and will create models. He is currently developing curriculum and models for two CC projects: Logging Opportunities in Online Programs for Science and High-Adventure Science. At TERC, he directed projects creating elementary and high school probeware and curricula on topics in physical science and engineering. Previously, he co-founded Alberti's Window, a small-business devoted to exploiting the potential of video in science education, developing and bringing to market both 2- and 3-dimensional video motion detectors. For Alberti's Window, he was Principal Investigator on two NSF-funded SBIR grants. He holds a Certificate of Advanced Study from Harvard University in Applied Electronics and a bachelor's and master's degree in music.

The Agile Programming Team. CC has one of the most versatile and experienced programming team in educational research, consisting of eight full-time programmers and several members of the scientific staff who program.

PROJECT ADVISORY COMMITTEE

Dr. Terrance Bensel is a professor and chair of the Department of Environmental Science at Allegheny College. He will consult on the project by working extensively with the team during the module development and will provide expertise on content, engagement, and pedagogy.

Dr. Tamar Shapiro-Ledley is a senior scientist at TERC who has extensive experience in ESS education and climate literacy. She is currently the PI on the Climate Literacy and Energy Awareness Network Pathway project. She will advise us on effective use of the educational materials in the classroom and will review the materials produced.

Dr. Mark Chandler is climate scientist at NASA Goddard Institute for Space Studies and will provide critical feedback on the modules and models. His primary research is on paleoclimate modeling. In addition he is leading a project to improve accessibility to complex computer climate models by developing and disseminating Global Climate Change GCM models for post-secondary education.

Dr. Katherine McNeill is an assistant professor of science education at Boston College. She is a leader in educational research focused on helping students construct arguments and consider multiple explanations for evidence. She will advise us on effective methods for evaluating argumentation skills. Her experience conducting studies around explanations will be invaluable, and her insights will help us develop our research focus and tools.

Jenelle Hopkins is a current field test teacher for the HAS project. She will provide real-world practical insight into classroom challenges with the materials and field test the HAS:ESS materials. She currently teaches high school Earth Science classes in Las Vegas, Nevada. She has been teaching for 17 years. Prior to teaching, she was a field exploration and underground mine geologist.

Keith Wheeler is currently the Chair for the Commission on Education and Communication of the International Union for Conservation of Nature. He is also the Chair and CEO of ZedX, a corporation that is dedicated to improving agriculture through advanced technologies. He will provide insight into new technologies and policies around environmental practices.

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