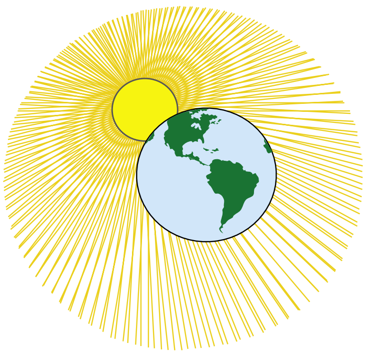
Global Systems Science and the *National Science Education Standards*



Contents

Lawrence Hall of Science
University of California
Berkeley, CA 94720-5200

GLOBAL SYSTEMS SCIENCE
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To be placed on our mailing list concerning future developments in the GSS program, and for summer institutes and workshops, please contact:

Global Systems Science
Lawrence Hall of Science
University of California
Berkeley, CA 94720-5200
Voice: (510) 642-0552
Fax: (510) 642-1055
email: agould{at}berkeley.edu

Global Systems Science
And the *National Science Education Standards*

by Cary Sneider
Lawrence Hall of Science
University of California, Berkeley, CA 94720-5200

1. Goals

Global Systems Science (GSS) is an interdisciplinary course for high school students. It is ideal for use in classrooms that include students with a wide range of abilities and a diversity of backgrounds and interests. The course draws on a variety of disciplines to illustrate how scientists investigate the ways that human activities interact with Earth systems. The GSS course has been under development for the past five years at the Lawrence Hall of Science, a public science center on the campus of the University of California at Berkeley.

GSS has received support from the Western Regional Center of the National Institute for Global Environmental Change (WESTGEC) to develop nine Student Books and a Teacher's Guide. Beginning in 1992, support from the National Science Foundation has made it possible for 125 high school teachers from 37 states to test the GSS Student Books with their classes, and to come to Berkeley, California, for three weeks to share their experiences and create new learning activities. Four of the GSS Student Books underwent two rounds of national trials, and their impact is was measured through a pre-post-test research study. Four more of the Guides were revised based on the first national trial tests and reviews by scientists, and one is published and undergoing trial tests.

As described briefly below, the content and pedagogy of the Global Systems Science course reflects the four goals which lie at the heart of the *National Science Education Standards* (NSES).

- GSS starts with real-world societal issues selected to evoke—among a broad spectrum of high school students—interest, excitement, and an appreciation of the value of science.
- Through laboratory activities, discussions, reading, and essay writing, students learn how billions of decisions made by people around the world affect the global enviornment, and reflect on the impact of their own daily decisions.
- The students are encouraged to discuss their changing perspectives on crucial societal issues related to science and technology.
- Students are motivated to continue their study of technical fields as they encounter a wide diversity of role models featured in the GSS Student Books.

Quotes from the National Science Education Standards (NSES)

The intent of the Standards can be expressed in a single phrase: Science standards for all students. The phrase embodies both excellence and equity. The Standards applies to all students, regardless of age, gender, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science. (NSES, page 2)

Effective science curriculum materials are developed by teams of experienced teachers, scientists, and science curriculum specialists using a systematic research and development process that involves repeated cycles of design, trial teaching with children, evaluation, and revision. (NSES, Program Standard B, page 213)

Students...are able to...

- *experience the richness and excitement of knowing about and understanding the natural world;*
- *use appropriate scientific processes and principles in making personal decisions;*
- *engage intelligently in public discourse and debate about matters of scientific and technological concern; and*
- *increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers.*

— NSES, page 13

GLOBAL SYSTEMS SCIENCE

2. Overview of the GSS Course

This paper will discuss, in some detail, how the GSS Student Book, *Climate Change*, addresses the four goals that underpin the *National Science Education Standards*. The paper will conclude with suggestions for improving and implementing the course, from the perspective of the *National Standards*. But first, in order to set the discussion into a broader context, we'll take a brief look at the GSS course as a whole, referring to the diagram on the previous page.

The first of the nine guides, A New World View, *introduces the concept of Earth systems. It provides an introduction to systems concepts, a vision of the diversity and unity of our planet, and examples of how certain conceptual tools, such as feedback and equilibrium, can be used to learn about the interaction between human activities and Earth systems. The systems concepts introduced in this Guide are revisited and applied in each of the other Student Books. Emphasis on systems thinking throughout the course is consistent with the discussion of Unifying Principles on pages 115-116 of the NSES. As shown in the illustration, the remaining eight guides are organized into three groups:*

- ***Key Global Problems*** *includes three guides, each concerned with a societal issue that lies at the interface of human activities and Earth systems. Student Books in this group are:* Climate Change, Ozone, *and* Losing Biodiversity.
- ***Fundamental Earth Systems,*** *includes three guides which address the principles, concepts, and theories that allow for a deeper understanding of Earth systems. Student Books in this group are:* Life and Climate, Ecosystem Change, *and* Energy Flow.
- ***Underlying Causes and Potential Solutions*** *includes two guides, each concerned with one of two major factors underlying human-induced global environmental change:* Population Growth *and* Energy Use.

All of the Student Books can be used together for a two or three semester course at the beginning of an articulated high school science program; or the Guides can be used individually to complement and enrich traditional science courses. Several different ways of sequencing the nine Student Books to create a curriculum are suggested in the GSS Teacher's Guide.

The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation. The units of investigation can be referred to as "systems." A system is an organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, numbers, transportation, and education. Systems have boundaries, components, resources, flow (input and output), and feedback.

The goal of this standard is to think and analyze in terms of systems...The idea of simple systems encompasses subsystems as well as identifying the structure and function of systems, feedback and equilibrium, and the distinction between open and closed systems. (NSES, K-12 Standard, page 116)

Human beings live within the world's ecosystems. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption. Human destruction of habitats through direct harvesting, pollution, atmospheric changes, and other factors threaten current global stability, and if not addressed, ecosystems will be irreversibly affected. (NSES, 9-12 Standard C, page 186)

Use of all nine Student Books in the first three or four semesters of high school will expose students to a substantial number of the fundamental principles, concepts, and theories in all seven content standards listed for the 9-12th grade levels, setting the stage for additional courses that will revisit the core content at a higher level in future years.

...teachers and school district personnel usually begin the design and development of a curriculum that meets local goals and frameworks with a careful examination of externally produced science materials.

...In designing curricula, care should be taken to return to concepts in successive years so that students have the opportunity to increase and deepen their understanding and ability as they mature. (NSES, Program Standard B, page 213)

The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations were information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest. (NSES, 9-12 Standard G, page 201)

3. How Does *Climate Change* Reflect the Goals of the NSES?

It was difficult to decide which of the nine Student Books to feature in this paper. The introductory Book, *A New World View*, features unifying principles. The Guides concerned with fundamental Earth systems—*Life and Climate*, *Energy Flow*, or *Ecosystem Change*—each address a great many concepts and theories listed under the Physical, Life, and Earth and Space Science Standards. *Energy Use* emphasizes the Technology Standard, while *Population Growth* emphasizes the Standard concerned with Science in Personal and Social Perspectives.

In the end, *Climate Change* was selected because it is unusual for a high school science text. Rather than presenting the familiar and accepted concepts and theories of science, it addresses a controversial topic—the theory of global warming—thus illustrating the History and Nature of Science as described in Standard G. In addition, global climate change is an excellent illustration of the relationship between certain scientific and technological issues and personal and societal decision-making. In the next section, we'll consider how *Climate Change* reflects the four fundamental goals, and all seven content standards for grades 9-12.

Goal #1 Students... are able to.... experience the richness and excitement of knowing about and understanding the natural world.

One challenge to teachers of science and to curriculum developers is making science investigations meaningful. Investigations should derive from questions and issues that have meaning for students. Scientific topics that have been highlighted by current events provide one source, whereas actual science- and technology-related problems provide another source of meaningful investigations. (NSES, 9-12 Standard A, page 173)

The first of the four goals identified in the *National Science Education Standards* has a strong emotional component. Students are not expected to just *learn* science content. They are expected to *experience the richness and excitement* of knowing about and understanding the natural world.

Climate Change is designed to engage student interest starting with the first chapter by presenting a societal issue that is of the utmost importance for life on Earth, yet is so controversial that we can witness scientists arguing vehemently with each other in a public forum. The issue of an enhanced greenhouse effect due to human activities is a magnificent "window on science" that demonstrates both the nature of science, and the human qualities that come into play, to a degree that would be impossible with classical science topics alone.

On the first page, the students learn about the worldwide climatic extremes of 1988—including droughts, floods, forest fires, and a super hurricane—and the electrifying Congressional testimony in the summer of that year by James Hansen, a NASA scientist, who claimed he was "99% certain that the globe will warm dramatically, by 3 to 9 degrees Fahrenheit, during the next century." On the next page, they read a clipping from the *San Francisco Chronicle* in which several prominent scientists vigorously attacked the evidence on which Hansen based his claim and strongly disagreed with his conclusions.

On the opposite page, the students find a 1996 article from *The New York Times,* reporting the results of a coordinated series of studies by 2,500 scientists from all over the world, which cautiously concluded that "... the observed warming is 'unlikely to be entirely natural in origin,' and that the weight of evidence 'suggests a discernible human influence on climate.'"

The students are asked to carefully examine the graphs that accompany the articles, plus any other evidence given to support different claims, to compare and contrast statements made by individual scientsts, and to identify views supported by a majority. Finally, they are asked to decide whether or not they think Hansen's conclusions were justified at the time, and whether or not the evidence they have seen so far supports his views today.

The first and second chapters get the students' attention. They quickly realize that *Climate Change* is not a typical science unit. Yet emphasizing the controversy presents a danger. Some students may conclude that the issue is not worth studying. After all, if the *scientists* can't agree, then what hope do *students* have of understanding the controversy? This potential pitfall is headed off in the next chapter, entitled "What Is the Controversy About?" In this chapter, students learn about the following points of agreement and disagreement concerning global climate change, and the current status of research on each:

Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.

Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. (NSES, 9-12 Standard G, page 201)

As more complex topics are addressed, students cannot always return to basic phenomena for every conceptual understanding. Nevertheless, teachers can take an inquiry approach as they guide students in acquiring and interpreting information from sources such as libraries, government databases—or as they gather information from experts from industry, the community, and government.... When secondary sources of scientific knowledge are used, students need to be made aware of the processes by which the knowledge presented in these sources was acquired and to understand that the sources are authoritative and accepted within the scientific community. (NSES, Teaching Standard A, page 31)

Teachers of science should engage students in conversations that focus on questions, such as "How do we know?" "How certain are you of those results?"..."Is there an alternative scientific explanation for the one we proposed?" ....Questions like these make it possible for students to analyze data, develop a richer knowledge base, reason using science concepts, make connections between evidence and explanations, and recognize alternative explanations. (NSES, 9-12 Standard A, page 174-5)

...students find that the geologic record suggests that the global temperature has fluctuated within a relatively narrow range, one that has been narrow enough to enable life to survive and evolve for over three billion years. They come to understand that some of the temperature fluctuations have produced what we perceive as dramatic effects in the Earth system, such as the ice ages and the extinction of entire species. They explore the regulation of Earth's global temperature by the water and carbon cycles. Using this background, students can examine environmental changes occurring today and make predictions about future temperature fluctuations in the Earth system. (NSES, 9-12 Standard D, page 188)

Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter. (NSES, 9-12 Standard B, page 180)

What we know:

1. The natural greenhouse effect keeps our atmosphere 33°C warmer than it would otherwise be, making it possible for life to exist on Earth.
2. The concentration of greenhouse gases in the atmosphere is increasing.
3. Theories, experiments, and observations of other planets converge on the prediction that if the concentration of greenhouse gases continues to increase, Earth will warm up.

Questions still being investigated:

1. Have we already observed a change in climate?
2. If global warming is under way, is it partly due to human activities, or is it entirely due to natural causes?
3. Has global warming already caused an increase in floods, droughts, and forest fires?
4. When will the concentration of greenhouse gases be twice that of the pre-industrial age?
5. If the concentration of greenhouse gases doubles, how warm will it get?
6. How will life be affected if the predicted warming occurs?

Current research on each of the outstanding questions is briefly summarized. For example, in reference to question 2, students look at a graph of global average temperature, showing how Earth has warmed and cooled due to natural processes over the last 200,000 years, and consider alternative interpretations of the data. In response to question 6, students review the 1996 report of the International Panel on Climate Change, which represents a broad consensus of scientists worldwide on how predicted climate changes over the next century are likely to affect people.

Throughout this chapter, students are asked to reflect on how the current state of research on global climate change demonstrates that science is not only a body of knowledge; but a dynamic, vital, and absolutely essential approach to understanding our world.

Yet learning *about* scientific research on global warming and the greenhouse effect is not sufficient. To *understand* the theory of global warming due to the increase in greenhouse gases, students need to explore the scientific underpinnings of the theory. That is the aim of Chapter 4 What's So Special About CO_2?

In Chapter 4, students read a brief overview of the historical development of the particulate theory of matter and the wave theory of light, and reflect on what they already know from personal experience about how light and matter interact in familiar situations. They experiment with a TV remote control device (which is actually an infrared emitter) to discover that although infrared light cannot be seen, it can reflect off of walls and ceilings.

But to fully understand how the interaction between infrared energy from the sun, and molecules of gas in the atmosphere result in (natural or human-induced) global warming, the students need to answer a fundamental question: Why is infrared energy absorbed by greenhouse gases, such as carbon dioxide and methane, but not by oxygen or nitrogen?

To answer this question in an intuitive and satisfying way, the students construct models of gas molecules commonly found in the atmosphere—oxygen, nitrogen, carbon dioxide and methane. By shaking the models at different frequencies they physically experience the phenomenon of reson*ance*, the mechanism by which energy is transferred from infrared energy to molecules of carbon dioxide and methane, but not to oxygen and nitrogen. This finding forms the basis for a deeper understanding of the greenhouse effect, which had been presented in a simpler form earlier in the book. Students also compare and contrast the greenhouse effect in a greenhouse with what actually occurs in the Earth's atmosphere.

Equipped with a better understanding of the greenhouse effect, the students "travel" to Mauna Loa Observatory in Chapter 5, How Do We Measure Carbon Dioxide? There the students meet scientists, technicians, and student assistants who are conducting the now-famous research that has led to the conclusion—supported by virtually all scientists involved in climate research—that the concentration of carbon dioxide is increasing in the atmosphere. Through pictures and interviews, the students see how the technology to measure carbon dioxide concentration has improved over the decades, and they conduct chemistry experiments in the classroom to measure the concentration of carbon dioxide in gas samples, answering questions such as: Is there more carbon dioxide in car exhaust or human breath?

In Chapter 6 Is the Atmosphere Really Changing? the students analyze actual data from Mauna Loa and other sites, discovering the relationship between atmospheric carbon dioxide and seasonal changes in the biosphere in different parts of the world. Chapter 7 What Are the Greenhouse Gases? completes the global picture of the sources and contributions of different greenhouse gases to the enhanced greenhouse effect.

In chapters 1-7 we learn that the outcome of scientific research is not a simple answer about what we

Understanding of the microstructure of matter can be supported by laboratory experiences with the macroscopic and microscopic world of forces, motion (including vibrations and waves), light, and electricity. (NSES, 9-12 Standard B, page 177)

Models help scientists and engineers understand how things work. (NSES, K-12 Standard, page 117)

Science often advances with the introduction of new technologies. (NSES, 9-12 Standard E, page 192)

Students also need to learn how to analyze evidence and data. The evidence they analyze may be from their investigations, other students' investigations, or databases. (NSES, 9-12 Standard A, page 174)

Usually, changes in science occur as small modifications in knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. (NSES, 9-12 Standard G, page 201-2) should do; but a series of "if...then" scenarios about the degree and timing of global warming given different paths of worldwide population growth and energy usage. These paths depend on human decision-making, at a global, national, and personal level. As citizens of an industrial nation, our students will play a very important role in making these decisions within the next few years. That brings us to the next goal of the *National Science Education Standards.*

Goal #2 Students... are able to.... use appropriate scientific processes and principles in making personal decisions.

Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society. (NSES, 9-12 Standard G, page 201)

Many high school students hold the view that science should inform society about various issues and society should set policy about what research is important. In general, students have rather simple and naive ideas about the interactions between science and society. There is some research supporting the idea that S-T-S (science, technology, and society) curriculum helps improve student understanding of various aspects of science- and technology-related societal challenges. (NSES, page 197)

Collectively, the billions of decisions made by people around the world every day have a profound effect on the world's climate. Discussion about the important role of individual decisions begins in Chapter 8 What Are Governments Doing About Climate Change? In this chapter, the students witness an actual Congressional hearing in which representatives of various government agencies present President Clinton's "Climate Change Action Plan," which represents the commitment of the United States to an international treaty on climate change that was signed by President Bush in 1992. Students have an opportunity to observe scientists respond to some disarmingly simple questions from the non-scientists (the members of Congress) whose job it is to decide what to do about global climate change.

At the conclusion of the chapter, the students learn that great strides have been made by one part of the plan, in which the Federal government encourages corporations to reduce the burning of fossil fuels by installing new efficient lighting fixtures and other energy-saving devices. Participating corporations save millions of dollars annually in energy bills, while significantly reducing the emission of greenhouse gases.

Unfortunately, according to a report in the *New York Times* on November 28, 1995, the reductions in greenhouse gas emissions achieved by the government program have been swamped by the increasing popularity of "sport" vehicles, which are larger and get lower gas mileage than typical small and medium-sized cars. Increased speed limits and longer average annual driving mileage per car has added even more to the annual greenhouse gas emissions produced by the United States, making it unlikely that we will meet our promised obligation to the international treaty on global warming.

At the conclusion of Chapter 8, the Teacher's Guide offers a laboratory activity in which students calculate how much carbon dioxide enters the atmosphere for each gallon of gas that is burned. (The answer is surprisingly large—about 10 kilograms.) As part of the discussion which follows the activity, students are asked to imagine that they are about to buy a car, and to think about what they might take into account if they were in a position to choose between a large "sport" vehicle and a compact "hatchback."

In this and other activities, teachers are urged *not* to advise students about what decision is best; but to help students recognize that there are a number of legitimate factors that enter into each personal decision, and there is no single "right" choice for everyone.

The teacher's role in these small and large group interactions is to listen, encourage broad participation, and judge how to guide discussion—determining ideas to follow, ideas to question, information to provide, and connections to make. (NSES, page 36)

Goal #3 Students... are able to.... engage intelligently in public discourse and debate about matters of scientific and technological concern.

The Global Systems Science course is based on the belief that all students can improve their abilities to engage in intelligent discourse and debate about matters of scientific and technological concern by:

a) learning about the scientific and technological background of the issue, as in Chapters 1-7;
b) observing others discussing the issues, as in the Congressional hearing in Chapter 8; and
c) engaging in discourse and debate themselves, which is the focus of Chapter 9, What Do You Think About Global Climate Change?

While the opportunity to discuss matters of scientific and technological concern is perhaps the most important way of achieving the goal, it is not simple. Class discussions and debates need to be structured so that the students are motivated to consider the issue from different points of view, have opportunities to restructure their thinking, and feel that their ideas and opinions will be heard and respected.

Understanding basic concepts and principles of science and technology should precede active debate about the economics, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges. (NSES, 9-12 Standard F, page 199)

As a springboard for discussion, at the beginning of Chapter 9 students are asked what they think about the statement of one of the scientists during the Congressional debate, that it might not be appropriate for him—as a scientist—to say what should or should not be done about the possibility of global warming.

Next, the students are asked to imagine that they are members of Congress who must decide whether the country should take strong action, moderate action, or no action at all to curb the emission of greenhouse gases. Before meeting in small groups to decide what

Science and technology are essential social enterprises, but alone they can only indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge. (NSES, 9-12 Standard F, page 199)

Using a collaborative group structure, teachers encourage interdependency among group members, assisting students to work together in small groups so that all participate in sharing data and in developing group reports. Teachers also give groups opportunities to make presentations of their work and engage with their classmates in explaining, clarifying, and justifying what they have learned. (NSES, page 36)

Teachers encourage informal discussion and structure science activities so that students are required to explain and justify their understanding, argue from data and defend their conclusions, and critically assess and challenge the scientific explanations of others. (NSES Teaching Standard E, page 50)

they should do, they read and discuss a balanced array of different viewpoints on what might be done, from the perspective of economics, politics, and ethics.

After an opportunity to discuss and come to agreement on their position, the small groups each present their report to the class, and students have opportunities to argue and debate as they share a diversity of different viewpoints. At the end of the unit, each student is asked to write an essay describing and justifying their personal viewpoint about global climate change. The instructions for the essay ask the students to start by deciding on a position and discussing their ideas with classmates. They should then revise their position, or decide how to take objections into account, before writing the final document.

Goal #4 Students... are able to.... increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers.

In particular, the commitment to science for all implies inclusion of those who traditionally have not received encouragement and opportunity to pursue science—women and girls, students of color, students with limited English proficiency. (NSES, page 221)

Many scientific investigations require the contributions of individuals from different disciplines, including engineering. (NSES, 9-12 Standard E, page 192)

High school is an important time in the development of every individual. The student's known universe expands from a small circle of friends, family, and community to encompass the entire world with all of its many cultures. High school students come to realize that they are leaving childhood behind, and they start to look for career possibilities. The choices they make at this time in their lives are crucial. Decisions about whether or not to take another course in mathematics or science, or to take a college admissions test, can close off future options, or open the door to counteless possibilities.

The degree to which students will make productive use of what they learned in high school science classes will depend, in large measure, on the choices they make early in their high school years. Built into the design of the GSS course is a conscious effort to motivate students to learn more about science and mathematics, by presenting interesting topics with relevance to people's lives, and by including photographs and information about a diversity of men and women who are making contributions to science as they pursue a wide variety of different educational and careers paths.

In *Climate Change*, for example, the students do not just meet the scientists who received the credit for the discovery of increased levels of carbon dioxide in the atmosphere. They also meet some of the technicians who take the measurements, the engineers who keep the equipment working, and the student assistant who spends her summers checking the data to make certain that there are no mistakes.

In summary, students who study *Climate Change* learn about the basic principles, concepts and theories related to global climate change in Chapters 1-7, but then revisit these ideas as they discuss what to do in light of uncertain scientific knowledge. In Chapters 8 and 9 the students "listen in" as members of Congress and scientists discuss how to prevent possible global warming in the future. Then, in chapter 9, the students discuss, debate, and write about their positions on the issues discussed in the unit. Illustrations of working scientists, technicians, and college students show that science is a human endeavor that offers a wide variety of exciting career opportunities.

Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. (NSES, 9-12 Standard G, page 200)

4. How Can *Climate Change* Be Improved?

The Global Systems Science course is still under development. Over the next year, revisions will be made based on feedback from National Trials and from scientists who are reviewing the Student Books for accuracy. Consequently, there is still time to substantially revise the materials so they are fully consistent with the *National Science Education Standards*. At present, we see at least two major improvements that are needed to bring the materials into alignment with *National Standards*. The first is to provide structured opportunities for students to be involved in full investigations—raising their own questions about climate change, and devising ways to answer the questions. The second is to find a mechanism to update the materials frequently so that they will continue to be scientifically accurate.

The need for full investigations. As illustrated in the previous discussion, the content of Climate Change is consistent with the NSES goals and content standards. However, this paper has barely touched on the laboratory activities which lie at the core of any science education program.

Two laboratory activities are included in the Student Book *Climate Change*. The first is a chemistry lab in which students measure the concentration of carbon dioxide in different samples of gas to answer the question: Is there more carbon dioxide in human breath or in car exhaust? In the other activity they construct molecular models of common atmospheric gases and uses these to answer the question: Why do carbon dioxide and methane absorb infrared energy, while oxygen and nitrogen do not? Neither of these are full investigations, in which the students formulate a question and devise an experiment or other procedure to answer it.

...in a full inquiry, instructional strategies such as small-group discussions, labeled drawings, writings, and concept mapping should be used by the teacher of science to gain information about students' current explanations. (NSES, 9-12 Standard A, page 174)

Teachers focus inquiry predominantly on real phenomena, in classrooms, outdoors, or in laboratory settings, where students are given investigations or guided toward fashioning investigations that are demanding but within their capabilities. (NSES, Teaching Standard A, page 31)

The GSS Teacher's Guide provides several other activities that were developed by high school teachers who attended the GSS institutes in 1992-1994. These include laboratory studies that answer other interesting questions, including:

- *How does convection drive global ocean currents?*
- *How does temperature affect the capacity of the ocean to absorb carbon dioxide?*
- *How does an atmosphere enriched in carbon dioxide affect photosynthesis?*
- *What are the physical properties of carbon dioxide?*
- *How do nutrients and light affect the ability of plants to absorb carbon dioxide?*
- *Will melting of polar ice provide positive feedback to increase global warming?*
- *How much carbon dioxide is produced by burning a gallon of gas?*
- *How much energy do different atmospheric gases absorb from the sun?*

Each of these questions is concerned with an important aspect of global climate change. Several are concerned with certain aspects of the carbon cycle (which is fully presented in the GSS Guide Life and Climate), and others are related to the greenhouse effect and possible feedbacks. In addition, each question involves laboratory investigations with real phenomena that the students can experiment with.

We have taken care in writing and revising these laboratory activities to leave many of the details of experimental design and data collection and analysis up to the students. However, in light of the N*ational Standards*, it is clear that we have left out a very important element—a full investigation in which students formulate the question to be answered, as well as the means of answering it.

Development of this aspect of the course will be challenging. We will need to start this open-ended activity when the students have enough information to ask intelligent questions, and we'll need to structure it so that they can generate testable hypotheses. We'll also need to test the approach in the classroom, and provide ideas for teachers to assess student performance. Nonetheless, we are committed to this approach, so that Global Systems Science will provide the full array of inquiry-based learning opportunities described by the *National Science Education Standards*.

The need for updates. Most instructional materials for high school science are hard cover books which feature classical science topics. Once drafts of these textbooks are reviewed by scientists, they will continue to be scientifically accurate in most details for at least

Because direct experimentation is usually not possible for many concepts associated with Earth and space science, it is important to maintain the spirit of inquiry by focusing the teaching on questions that can be answered by using observational data, the knowledge base of science, and processes of reasoning. (NSES, 9-12 Standard D, page 188-189)

Because it plays a central role in establishing and maintaining Earth's climate and the production of many mineral and fossil fuel resources, the students' explorations are also directed toward the carbon cycle. (NSES, 9-12 Standard D, page 187)

In the National Science Education Standards, the term "active process" implies physical and mental activity. Hands-on activities are not enough—students also must have "minds-on" experiences. Science teaching must involve students in inquiry-oriented investigations in which they interact with their teachers and peers. Students establish connections between their current knowledge of science and the scientific knowledge found in many sources; they apply science content to new questions; they engage in problem solving, planning, decision-making, and group discussions; and they experience assessments that are consistent with an active approach to learning. (NSES, page 20) five to ten years—until the next adoption cycle for most school districts.

Global Systems Science is different. Topics such as global climate change, ozone depletion, and loss of biodiversity are "hot" issues at the frontiers of science. Articles heralding new research results and changes in scientists' perceptions on substantive issues appear in virtually every issue of popular magazines such as *Science News*, the *New York Times*, the *New Scientist,* and *Scientific American*, as well as refereed journals such as *Nature, Science,* and dozens of others.

It is not enough for the Teacher's Guide to urge teachers to keep their bulletin boards up to date. Not all teachers have the time to read journals and browse the World Wide Web. Furthermore, many of the research articles need to be summarized, or turned into an activity, for students to grasp what was done, and how the results are related to the topic of global climate change. This work needs to be done by a dedicated staff, and the material needs to be provided regularly to teachers who are using the GSS materials.

We are currently exploring options for delivering the GSS instructional materials in ways that satisfy current requirements for program adoption (such as hard cover books), practical classroom needs (such as inexpensive lab materials); and frequent updates (though newsletters and easy computer access.)

Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. (NSES, 9-12 Standard A, page 175)

The subject matter in the physical, life, and earth and space science standards is central to science education and must be accurate. (NSES, Criteria for the Content Standards, page 109)

5. What Would Be Needed to Implement *Climate Change?*

The GSS materials have been developed with a vision of effective teaching in mind. Recognizing that some students skim text materials just to answer the questions at the end of the chapter, we have no end-of-chapter questions. Instead, we embed a few questions in the text to stimulate reflection, and provide other questions in the Teacher's Guide to stimulate small group discussion in class. To reduce emphasis on word definitions in favor of conceptual understanding, we have no glossary, and introduce a minimum of new terms in the student materials. We provide specific suggestions for teaching the activities and reading materials, that is consistent with the following advice given in the introduction to the GSS Teacher's Guide:

> *"If the key to effective learning could be summed up in one word, it would probably be "interaction." Getting your students to discuss the issues, to disagree and challenge each other, to collaborate on laboratory problems, and to help each other in homework activities are all effective ways to increase interaction. The*

Science is often a collaborative endeavor, and all science depends on the ultimate sharing and debating of ideas. When carefully guided by teachers to ensure full participation by all, interactions among individuals and groups in the classroom can be vital in deepening the understanding of scientific concepts and the nature of scientific endeavors. The size of a group depends on age, resources, and the nature of inquiry. (NSES, page 31-32) *more interaction your students experience in this course, the more likely they will be to think about what they read, to remember it, and to care about what is really happening in and to our world." (GSS Teacher's Guide, page 14)*

Integrated and thematic approaches to curriculum can be powerful; however, they require skill and understanding in their design and implementation. (NSES, Program Standard B, page 213)

The program standards are rooted in the assumptions that thoughtful design and implementation of science programs at the school and district levels are necessary to provide comprehensive and coordinated experiences for all students across grade levels, and that coordinated experiences result in more effective learning.

The district and school must provide curriculum frameworks that highlight inquiry and the support of materials and time to make this type of teaching possible. (NSES, Program Standard A, page 210-211)

We recognize that a statement of this sort is only useful for teachers who already have the necessary skills for using an inquiry approach, Teachers who do not have these skills are likely to use the materials in a way that fails to capture student interest and engage students' critical and creative thinking processes.

Consequently, we are developing a model for teacher education that we call "Teacher-as-Curriculum-Developer." This approach will be described in a forthcoming book about strategies for teacher education in mathematics and science that is currently under development by Susan Loucks-Horsley and Peter Hewson of the National Institute for Science Education (NISE). In brief, the approach involves the science teacher as a member of a team to build on what is currently available, and to adapt and invent elements to bring the program to life for the students.

This strategy has been used to shape the GSS program to the current stage of development. The teachers who helped develop the materials are enthusiastic, committed to an inquiry approach to teaching, and creative in adapting the GSS materials to the needs and interests of their students.

The difficulty will be in the next stage of scaling-up the program for use by thousands of teachers nationwide. The approach we will take is to form interdisciplinary teams at the school and district level to *create* a GSS curriculum that meets local needs. At this next stage of implementation, the teams will have complete sets of carefully developed and tested materials to start with, so the burden of developing new activities and student materials will be reduced. However, there will be many opportunities for the teams to be creative in selecting and sequencing the materials, planning the overall flow of ideas in the curriculum, identify local resources and field trip sites, and coordinating the science curriculum with other subjects. Provision will also be made for implementation teams to participate in a national network, including other GSS teachers, program staff, and scientists. Communication will be through newsletter and Internet connection to exchange innovative ideas, ask questions, and develop a sense of community and collaborative effort.

Another aspect of the implementation plan is to further develop authentic assessment tools. At present, the Teacher's Guides offers a general discussion of portfolios, and three different tasks for use before and after teaching each unit, to assess student learning. These include: a) open-ended discussion of a thought-provoking cartoon depicting the interactions between people and nature; b) a concept map; and c) a short essay-style questionnaire related to the objectives of the unit. As we examine pre-post-test data during the summer of 1996, we will develop a rubric so that teachers can assess student progress. Additionally, we will continue work on other approaches to assess changes in students' abilities to apply their understanding, attitudes, and skills to real-world situations.

And finally, as the Global Systems Science program gets underway in schools and districts nationwide, we will work directly with other elements of the educational system to evolve new approaches to educating and supporting teachers, and to changing the teaching of science at tertiary institutions to support the new reforms. For example, the GSS staff will join the Earth System Science Education (ESSE) program, a consortium of universities that include courses for undergraduates on global environmental change, to exchange ideas and information, and to advise students who are so excited by the GSS course that they wish to pursue global studies at the college level.

In the vision of science education described in the Standards, many planning decisions are made by groups of teachers at grade and building levels to construct coherent and articulated programs within and across grades. (NSES, Teaching Standard A, page 32)

Assessment tasks are not afterthoughts to instructional planning, but are built into the design of the teaching.

Analysis of student assessment data provides teachers with knowledge to meet the needs of each student. It gives them indicators of each student's current understanding the nature of each student's thinking, and the origin of what each knows. (NSES, Teaching Standard C, page 38)

Another important shift is toward "authentic assessment." This movement calls for exercises that closely approximate the intended outcomes of science education. Authentic assessment exercises require students to apply scientific knowledge and reasoning to situations similar to those they will encounter in the world outside the classroom, as well as to situations that approximate how scientists do their work. (NSES, page 78)

The Standards took an insightful and innovative step by suggesting that the responsibility for improving scientific literacy extends beyond those in classrooms and schools to the entire educational system. (NSES, page 20)