

**Global
Systems
Science
Teacher's Guide**

***Overview of
Global Systems Science***

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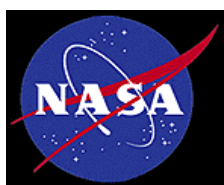
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To obtain latest revised editions of GSS books through University of California, Lawrence Hall of Science, please visit the GSS website:

<http://www.lawrencehallofscience.org/GSS/>

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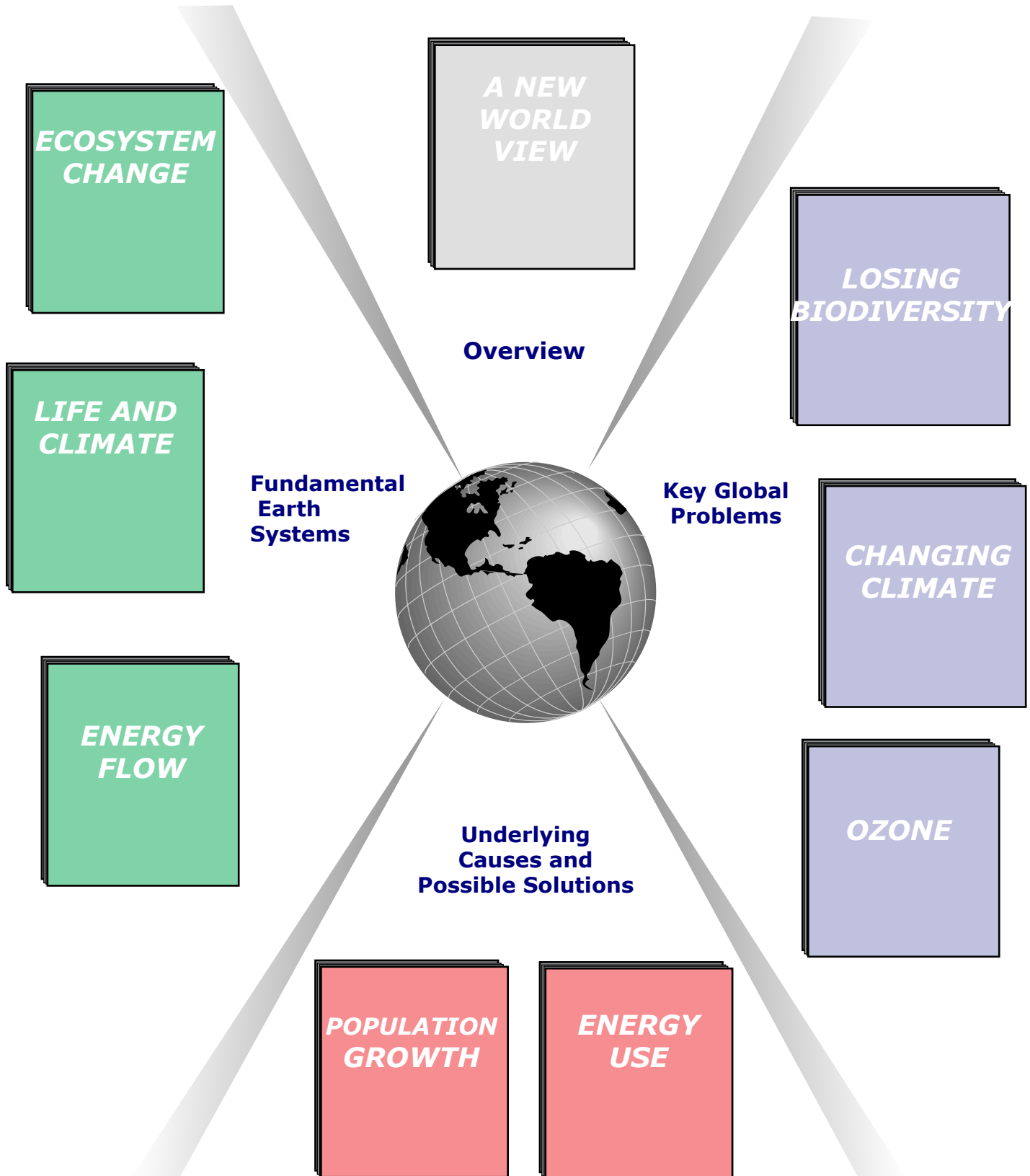
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Overview of Global Systems Science

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GLOBAL SYSTEMS SCIENCE



Map of the GSS Course

All nine of the Student Guides are shown in the map on the facing page and brief descriptions of each Student Guide is on the following pages. The map shows how the Guides can be divided into four groups, with the first Guide, *A New World View*, introducing the others. Various ways of sequencing the Guides in a one year course are suggested the “How Can I Customize GSS for My Students?” section. In planning your Global Systems Science course, it is helpful to keep in mind that *A New World View* is about 30 pages in length, and is intended to take no more than one or two weeks of daily instruction. All of the other Student Guides range in length from 75 to 100 pages, and each will require from three to six weeks of instruction.

GSS Teacher’s Guide—Overview

This is your *Global Systems Science Teacher’s Guide*. It is both online at the GSS website and printed on looseleaf paper so that you can remove or add certain sections, or easily copy pages to provide your students with additional laboratory activities. We recommend that you keep it in one or two looseleaf binders.

The first part of this guide is intended to answer the most commonly asked questions about the GSS course:

What will my students learn?

How can I customize GSS for my students?

What teaching methods should I use?

How can I assess student learning?

How is GSS Related to Science Education Reform?

What support do I need to implement GSS?

How was GSS created?

Who created GSS?

GSS Teacher’s Guide—Teaching Suggestions

The remainder of the Teacher’s Guide is divided into nine sections, keyed to each of the nine Student Guides pictured on the facing page. Each section has:

- A brief overview of the Student Guide and a list of its educational goals and objectives.
- Additional activities for various groups of students, including those who may have difficulty grasping some of the concepts, and those who are capable of meeting additional challenges.
- Suggestions for demonstrations, “openers,” small and large group work, and questions to stimulate your students’ thinking.
- A list of additional resources for enriching classroom instruction.

What is Global Systems Science?

Global Systems Science (GSS) is an interdisciplinary course for high school students that emphasizes how scientists from a wide variety of fields work together to understand significant problems of global impact. The “big ideas” of science are stressed, such as the concept of an interacting system, the coevolution of the atmosphere and life, the goal of a sustainable world, and the important role that individuals play in both impacting and protecting our vulnerable global environment.

GSS was developed by a collaborative team of teachers, scientists, and curriculum developers, so that it reflects both the cutting edge of modern interdisciplinary science, and the practical realities of the classroom.

The target audience for this course encompasses the entire range of high school students from grades nine through twelve. The series of Student Guides may be used for a one-year integrated science course; or individual guides may be incorporated into existing high school biology, physics, chemistry, Earth science, or social studies courses.

Global Systems Science involves students actively in learning. They perform experiments in the classroom and at home. They read and discuss background materials. They “meet” a selection of scientists, both men and women, from a variety of ethnic and educational backgrounds. They work together to dramatize their ideas for working toward solutions to worldwide environmental problems. They are challenged to make intelligent, informed decisions and to take personal actions, such as conserving energy, recycling, and preparing for their role as voting citizens in a modern industrialized society.

The GSS Student Books

The instructional materials for *Global Systems Science* consists of this Teacher’s Guide and nine Student Books, each of which focuses on a different aspect of global environmental change. Each Book contains laboratory experiments, home investigations, descriptions of recent scientific work, historical background, and consideration of the economic, political, and ethical issues associated with each problem area. Collectively, they constitute a unique combination of studies in the natural and social sciences through which high school students may view the global environmental issues that they will confront within their lifetimes.

The nine Student Books are divided into four areas: A New World View, Key Environmental Problems, Fundamental Earth Systems, and Underlying Causes and Possible Solutions. The nine books can be presented in any order except for the first one, *A New World View*, which introduces the GSS approach to the study of our planet. Each book is briefly described on the following pages.

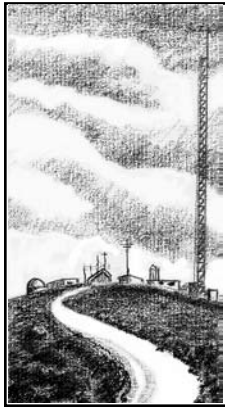


A New World View

introduces all of the other Guides in the *Global Systems Science* series, and presents four key ideas that thread through the entire course: First, the Earth has tremendously diverse environments, yet it is a single planet that we all call “home.” Second, we can better understand the Earth if we think of it in terms of systems. Third, everything is connected to everything else. And fourth, the goal of global studies is to find out what we can do to sustain life on Planet Earth—now and in the generations to come. To learn about the value of laboratory work for investigating Earth systems, students design and conduct controlled experiments to determine how to sustain life inside a terrarium.

Key Global Problems

Three Guides in the GSS series are concerned with environmental problems which affect the entire planet—climate change, depletion of the world’s ozone layer, and loss of species. These issues were selected because they are clearly global in nature, each represents a potential threat to life and prosperity on planet Earth, and each illuminates important aspects of the interaction between human activities and Earth systems.



Changing Climate

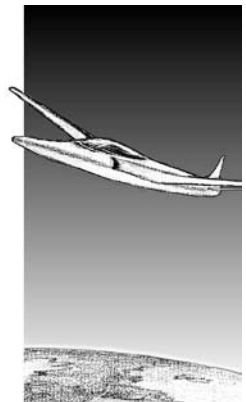
addresses the controversial question of how human activities may be changing Earth’s climate. It takes students on a “field trip” to Mauna Loa Observatory where they see how scientists have measured carbon dioxide in the Earth’s atmosphere since 1957. They

graph and interpret data from Mauna Loa and other observatories which led to the prediction, in 1988, that changes in our atmosphere will cause the entire globe to gradually warm up. They also measure carbon dioxide in the laboratory to find out how much is contained in a sample of human breath and car exhaust. The Guide goes on to show how the discoveries at Mauna Loa have been challenged by other scientists in the early 1990’s, and discusses the consensus of opinion about global climate change that finally emerged in 1995. The Guide identifies scientific questions which still remain unanswered, and

involves students in thinking about the economic, political, and ethical implications of regulating human activities to reduce the likelihood of global climate change.

Ozone

is a success story about how people around the globe are cooperating to solve a serious environmental problem. Ozone gas in the upper atmosphere shields our planet from ultraviolet light that is thought to cause skin cancer and cataracts in humans, and that may be harmful to a wide variety of plants and animals. The story of how the depletion of ozone came to be recognized and connected to the production of certain chemicals used in refrigerators, air conditioners, and the computer industry demonstrates that science can be an exciting and



adventuresome field, and that people in a wide variety of careers often play important roles in scientific discoveries. The fascinating epilogue in which more than 100 countries agreed to phase out the ozone-destroying chemicals clearly shows the connection between science and social action. Since ozone will continue to be depleted for several decades due to chemicals already in the atmosphere, your students will learn how to protect themselves by monitoring the levels of UV radiation in their community, and experimenting with sun block to see if it really offers protection from the ultraviolet rays of the sun.

Losing Biodiversity

is about the endangerment and extinction of entire species of plants and animals throughout the world due to human actions, beginning with the case study of the buffalo. Students learn about the value of biodiversity, from the discovery of new medicines and materials, to the protection of food crops and global systems. The current loss of biodiversity is put into perspective by involving the students in laboratory work where they see how species can adapt to changing conditions, learn theories about how new species evolve, and study the natural causes of extinctions. Further laboratory work illustrates the vital importance and fragility of soil in supporting entire communities of plants and animals; and how soil productivity is impacted by certain agricultural practices. Finally, students consider the history of actions that people around the world have taken to protect endangered species, up to current debates in Congress, and international agreements to preserve biodiversity.



Fundamental Earth Systems

The three student books which make up this portion of the *Global Systems Science* course put global environmental problems into context by focusing on the natural systems within which human activities occur. Such understanding is essential if we are to grapple with key global problems, and eventually find ways for humans to prosper and thrive without diminishing the rich diversity of life on Planet Earth.

Life and Climate

is about how our atmosphere and climate came to be as they are today; how life on Earth evolved; and how the evolution of life and climate have affected each other since the Earth was formed. In this Guide your students will find the story of how tiny plants brought oxygen to the Earth's atmosphere; and how changing climates may have brought about the evolution of our human ancestors in Africa five million years ago. They will construct timelines, and find out how we know where to place milestones in the development



of life. They will learn about the gradual acceptance of tectonic plate theory, and how the movement of tectonic plates is now thought to cause the climate changes that affected the evolution of life. In the laboratory, your students will experiment with dissolving rocks to explore the long term carbon cycle which has contributed to the long term stability of the Earth's climate. In the final chapter, they will consider what the Earth's past can tell us about its future.

Ecosystem Change

is about the interdependence of all living things and the nonliving environment. It is also about how human activities are changing ecosystems around the world. Through case studies your students will learn about the vastly different kinds of ecosystems, or biomes, on our planet. They will discover that humans have been changing ecosystems for thousands of years; but that the pace of change has increased with the rapid growth of human populations in the last century. In the laboratory, your students will investigate the variables that are important in the process of decomposition, and relate their findings to the biogeochemical cycles that maintain Earth's biosphere. Through interviews, they will "meet" scientists like Samira Omar of Kuwait, who is studying the ecological effects of the Gulf War; and Dr. Dagmar Werner, who is working to preserve the biodiversity of the rain forests of Central America. They will also find out what people in the United States are doing to reduce human impact on ecosystems, and consider ways that their own actions can make a difference.



Energy Flow

is about the way energy flows through the atmosphere, oceans, land, and living things. Analyzing the flow of energy is a very useful way to understand Earth systems. For example, through laboratory investigations, your students will explore the process of convection, and see how this process is used to understand earthquakes and volcanoes, global winds, and ocean currents. In other lab activities they will experiment with the variables that affect water flowing through a bottle, and then apply their insights about dynamic equilibrium to understanding how the greenhouse effect is expected to change the Earth's climate. In the last chapter your students will learn about how some of the energy that flows through living systems has been stored, over millions of years, in the form of fossil fuels; and how that energy is being released to power our civilizations for a few short decades. With this background, your students are asked to think about how the flow of energy through Earth systems affects their daily lives, and how life might be different for their children and grandchildren.



Underlying Causes and Possible Solutions

Two aspects of our modern age stand out as possibly the most important underlying causes of global environmental change—the rapidly growing human population, and the ways in which people use natural resources for energy. Yet within both areas there is reason to hope that intelligent decisions by individuals can reduce the impact of these problems and lead to a habitable world for future generations.

Energy Use

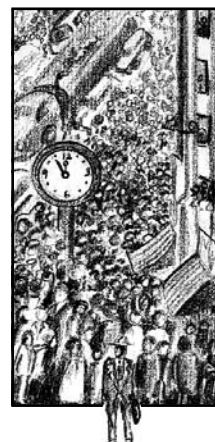
begins by inviting students to take an inventory of the ways that they use electricity. By "following the wires" back to a power plant, and from there to a grid of all power plants in the country, your students will begin to grasp the vast infrastructure that supports our way of life. Through laboratory experiments they will learn the basic principles on which electrical devices work; and through a brief history, they will learn how our national energy



policy came to be. They will also learn about the huge amounts of Earth materials that are used for transportation, home heating, and industry on a daily basis, and the small fraction of that energy that is actually put to use. In the last portion of the unit your students will conduct simple experiments in which they discover that conservation will allow us to maintain our current levels of energy usage while saving billions of dollars and reducing our impact on the environment. They will also explore new technologies for satisfying the energy needs of a growing human population while keeping the impact of energy use to a minimum.

Population Growth

addresses a fundamental problem: even if we can change our habits to use only clean and efficient sources of energy such as solar, wind, and water power, global environmental problems will continue to worsen if the world's population continues to grow at the present rate. Today there are over 5 billion people on Earth, and the population increases by one million every four days. Yet it is difficult for students to see the effects of population growth. They are therefore asked to think about the quality of their own lives as a starting point, and to recognize how satisfying their needs takes a share of the Earth's resources. By comparing their own lives with conditions in countries such as China and India, they will be in a better position to consider what may happen if the human population continues to grow as rapidly as it is today. Through mathematical investigations, your students will learn about factors that contribute to the rate of population growth, and the idea of carrying capacity, which relates an ecosystem to the populations it can sustain. The cultural and religious dimensions of efforts to curb population growth are sensitively discussed, and students are encouraged to form their own opinions about what can and should be done by individuals and by governments to control the growth of the global human population.



The overall goal of the Global Systems Science course is for students to become scientifically literate citizens, aware of the many ways that their lives are interconnected with the world around them. While many students who enroll in the GSS course may be moved to change their personal behaviors, or undertake projects to achieve a sustainable world, it is important for teachers to avoid telling students what they "should" do. Individual students may respond to the course in a variety of different, yet equally valid ways. The value of scientific literacy is that it gives individuals the power to make personal choices that are consistent with their growing knowledge and stature as world citizens.

What Will My Students Learn?

The overall goal of the *Global Systems Science* course is for high school students to become scientifically literate citizens. This means not only understanding basic concepts of science and how these concepts are arrived at, but also being able to *apply* that scientific knowledge to real world problems, and personal decision-making. Scientific literacy is important not only for individuals who eventually select career paths in technical fields, but for everyone in modern society.

In working towards this goal, the many teachers, scientists, and full-time curriculum developers who have worked together to develop the *Global Systems Science* course have agreed on the following specific goals that we hope students will achieve through the GSS course, on their way to becoming scientifically literate citizens.

1. **GSS students will grow to appreciate the unique qualities of Earth’s environment.**
2. **GSS students will increase their knowledge of the total Earth system.**
3. **GSS students will learn how human activities are changing the global environment.**
4. **GSS students will see how personal decisions can lead to a sustainable world.**

The GSS course rests on the assumption that students achieve long term goals such as these through a wide variety of experiences and activities. Consequently, each of the goals is addressed in a different way by each of the nine GSS Student Guides. The ways that each of the goals are expressed in each of the Student Guides is shown in the following table.

In contrast to **goals**, which are deeply-rooted changes in students’ understanding, **objectives** are tangible outcomes that we can expect students to achieve as they progress through a unit. Each section of the Teacher’s Guide which relates to a unit starts with a list of objectives that support the unit’s goals.

What Will My Students Learn?

GSS Students will...	1. Grow to appreciate the unique qualities of Earth's environment.	2. Increase their knowledge of the total Earth system.	3. Learn how human activities are changing the global environment.	4. See how personal decisions can lead to a sustainable world.
In <i>A New World View</i>, students...	...consider both the diversity of environments on Earth, and its unity.	...are introduced to the systems approach to studying the Earth.	...begin to think about how what we do affects future generations.	...realize that the world is a common resource that is shared by all.
In <i>Climate Change</i>, students...	...realize how our way of life depends on Earth's stable climate.	...grasp how the "greenhouse" effect controls Earth's climate.	...understand which human activities lead to an enhanced greenhouse.	...formulate a personal response to the possibility of global warming.
In <i>Ozone</i>, students...	...recognize how ozone in the stratosphere protects all life from UV rays	...understand how oxygen interacts with radiation in the atmosphere	...recognize how manmade chemicals are depleting the ozone layer	...see ways that they can help to close the ozone "hole."
In <i>Losing Biodiversity</i>, students...	...appreciate how we depend on the immense biodiversity of our planet	...recognize the interdependence of life in an ecosystem.	...identify the many human activities that are impacting other species.	...recognize the important roles that individuals play in preserving life.
In <i>Life and Climate</i>, students...	...recognize that today's climate and life evolved over billions of years	...learn about how life has affected climate and how climate has affected life.	...learn to distinguish between natural and manmade climate changes.	...recognize that small changes can result in major climate shifts.
In <i>Ecosystem Change</i>, students...	...appreciate the wide variety of ecosystems that occur on our planet.	...grasp the complexity of interactions that occur within an ecosystem.	...recognize the many ways that humans are changing ecosystems.	...find out how individuals are saving natural habitats.
In <i>Energy Flow</i>, students...	...realize how energy constantly flows around and through us.	...learn to identify sources and transformations of energy in Earth systems.	...understand how human actions can change the flow of energy.	...recognize how each person affects the flow of energy on the planet.
In <i>Population Growth</i>, students...	...realize how rapidly the human population is growing worldwide.	...use mathematics to model the ways that populations change.	...recognize how human population growth affects the global environment.	...realize that population growth is the result of many personal decisions.
In <i>Energy Use</i>, students...	...appreciate how Earth's finite resources provide for today's energy needs.	...grasp the vast dimensions of the world's energy infrastructure.	...recognize how our use of Earth's resources affects the environment.	...see how individuals can conserve energy, and use renewable resources.

How Can I Customize GSS for My Students?

Teachers who have tested the GSS materials have told us that there is a tremendous diversity of students who are interested and capable of studying *Global Systems Science*. But each individual and each group of students brings a different set of needs to the classroom. Also, the constraints of time, money, and prior curriculum planning may affect how you use these materials. Therefore, we have designed the GSS course for maximum flexibility, to enable you to customize the course for your particular teaching situation.

The first Guide, *A New World View*, presents the overall concept of systems, sustainability, and environmental ethics, as well as giving an overview of each of the other eight guides in the series. The other Guides may be used in any order, depending on the emphasis that you want to give the course, and what makes most sense to you. Assuming you meet with your students five hours per week, the introductory Guide will take about a week to present, and each of the other Guides will require about one or two months of instruction.

Many teachers have told us that their principals expect traditional course descriptions, but they can use the GSS Student Guides to replace several chapters of their regular textbooks. Although all of the GSS Guides are interdisciplinary, each one emphasizes one or two of the disciplines, so that they can easily be integrated into discipline-based courses.

If you teach...	You can substitute...	If you teach...	You can substitute...
Earth Science	<i>Life and Climate</i>	Biology	<i>Losing Biodiversity</i>
Physics (or Physical Science)	<i>Changing Climate</i> <i>Energy Flow</i> <i>Energy Use</i>		<i>Ecosystem Change</i> <i>Life and Climate</i> <i>Population Growth</i>
Chemistry	<i>The Ozone Hole</i>	Mathematics	<i>Population Growth</i>

Other teachers have told us that it is not difficult for them to use the GSS materials for a one or two semester course for 9th or 10th graders. Teachers from schools where courses in life science, physical science, or earth science are mandated organized the materials to emphasize these disciplines; but many were encouraged by their administrators to emphasize the interdisciplinary nature of *Global Systems Science*. Some were even able to cooperate with the social studies teachers in their school, and use the GSS materials for a course that emphasized Science and Society, either for incoming freshmen, or for a 12th grade "capstone" course.

Following are examples of different ways that teachers have organized the Global Systems Science materials to structure their programs.

Title: **Global Environmental Science**

Length: 1 Year

Semester I: *A New World View*

Changing Climate

Life and Climate

Energy Use

Semester II: *Losing Biodiversity*

Ecosystem Change

Energy Flow

Population Growth

Ozone

Title: **Global Change—Life Science**

Length: 1 Semester

A New World View

Life and Climate

Ecosystem Change

Losing Biodiversity

Population Growth

Title: **Global Change—Physical Science**

Length: 1 Semester

A New World View

Changing Climate

Ozone

Energy Flow

Energy Use

Title: **Global Change—Earth Science**

Length: 1 Semester

Life and Climate

Changing Climate

Energy Flow

Title: **Science and Society**

Length: 1 Semester

A New World View

Changing Climate

Losing Biodiversity

Population Growth

Energy Use

Course Descriptions

A course is more than a title and list of books. The concept behind the course needs to be clearly articulated for it to be approved by the Principal or Curriculum Committee, and—if it's an elective—to be chosen by students. So, at the most recent GSS Summer Institute, we asked teachers to write descriptions of GSS courses that they planned to teach. Following are their ideas:

GSS is a viable alternative to the existing grade 9 physical science program. It will cover most of the same content, but will do so in a more integrated and relevant way.

—Christopher Sullivan, East Longmeadow High School, East Longmeadow, Massachusetts

Global Systems Science is a course for high school students who care about the future of our world. It applies scientific knowledge to key global problems and searches for solutions.

—Diane Bernaciak, Hudson High School, Hudson, Ohio

This course blends the sciences with economics, mathematics, English, and history. It's a dynamic approach to the study of science with real life situations and problems used to illustrate the major concepts and processes and systems at work on the planet.

—Christine Donovan, Sunnyside High School, Tucson, Arizona

GSS introduces all aspects of science: chemistry, biology, physics, and earth science. Freshmen will get a good introduction to all the sciences. Most important, they will see how the different disciplines really work together and interrelate with each other. Students will benefit from hands-on, real-life science.

—Glenn (Skip) Swanzig, DuPont Manual High School, Louisville, Kentucky

GSS uses an integrated approach of chemistry, physics, and some biology to explain environmental issues. Modeling, systems mapping, and feedback loops are used to tie together seemingly unrelated topics.

— Brian Rogan, Dublin School, Dublin, New Hampshire

Current Science Events would be a two year course for all 9th and 10th graders, using all of the GSS guides. The students would learn science concepts and relate these to current global and local events. Each teacher would add their own strengths and experience to the course. — John Clarke, Tewksbury High School, Tewksbury, Massachusetts

Science and Society would be a one year course offered as an elective to juniors and seniors. It would be about the interaction of human activities and natural processes, and what can be done to achieve a sustainable world.

— Gary Courts, Miamisburg High School, Miamisburg, Ohio

Integrated Science would be a one year course for any student in grades 10-12. It will allow students to examine the physical, chemical, and biological aspects of how human population growth is affecting the world's climate, ecosystems, and biodiversity.

— Bonita Deiter, Jefferson West High School, Meriden, Kansas

The beauty of this course is its relevance to social issues. Science is seen as a tool to help us solve problems by clarifying causes and suggesting solutions.

— Anne Zellinger, Kahuku High and Intermediate School, Kahuku, Hawaii

GSS emphasizes how scientists work together to understand problems with global impact. It meets our school's requirement of being a lab course, and meets National Standards and recommendations. This course fits in with our science department's philosophy that science is for every student.

— Patricia Brown, Brownell-Talbot High School, Omaha, Nebraska

What Teaching Methods Should I Use?

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 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. Following are suggestions for increasing student interactions involving reading assignments and lab activities.

Reading the Student Guides

In order to make the GSS Student Guides accessible to as many students as possible, we have attempted to keep the vocabulary and sentence structure clear and simple, without sacrificing crucial information, concepts, or logical arguments. If your students are average readers, you should be able to give homework assignments of the appropriate length and expect your students to read and think about the materials, and come in to class ready to discuss it.

We recognize, however, that many students do not have the skills or the motivation to read text materials on their own. In that case, be inventive! Have teams of students work together in class on selected sections of the text, so that they can become the “experts.” Have different teams give oral reports to the class so that everyone is exposed to the various ideas, but the students do not have to read it all on their own. You could present some of the material in the form of lectures, discussions, and dramatizations or through some of the supplementary activities presented in the Teacher’s Guide.

If, on the other hand, your students are independent learners, with excellent reading and research skills, you may want to assign these materials as resources to be used for independent study, or by teams of students. You can require the students to obtain further information on their own, using the bibliographies at the end of each part of the Teacher’s Guide as starting points.

The variety of ways in which you can use the GSS materials to construct a course appropriate for your students may be constrained by your personal situation; but it is limited only by your imagination.

Evelyn Bradshaw from Cleveland Heights High School in Cleveland Heights, Ohio, suggests that a reading assignment can be cut into paragraphs. The scrambled paragraphs can then given to individuals or groups of students. The students must figure out the order of the reading, and in doing so, learn the meaning of the assignment more thoroughly.

Planning Lab Activities/ Investigations

The heart of any good science program is a set of laboratory activities that help students grasp fundamental concepts and enable them to participate in scientific investigations. Two primary laboratory activities are provided in each of the Student Guides, and other short activities are suggested throughout the student text materials. Additional activities are included in the sections of this Teacher’s Guide which correspond to the nine student units.

Before beginning a new unit, look over all of the activity suggestions, and decide which are most appropriate for your students. Do not try to do all of them! It is far better for your students to become deeply involved in a few key activities, and think about the results and implications of their discoveries than it is for them to “do” lots of lab work.

Once you have decided on a set of activities for the unit, you will need to gather the necessary materials and try the activities yourself. That will put you in a much better position to help your students when they follow the same paths and encounter some of the same difficulties.

Be prepared to shift gears if it appears that your students need to spend more time on a given experiment, either because they need to further develop their laboratory skills, or because they have ideas for improving the experiments, or using the techniques to answer new questions.

GSS activities are intended to be open-ended, allowing the students to identify variables and plan experiments within a general framework. Try not to constrain them too much at first. Even professional scientists flounder a bit before designing experiments that give them the kind of information they need to learn about the phenomenon under study. Try to play the role of a “coach” instead of a “director.”

When your students have finished their lab activities, they will need time—either in class or at home—to write a laboratory report. Specific suggestions for reports are provided for most of the lab activities in the student text materials; but you will undoubtedly have your own requirements as well. The lab reports provide another good opportunity for students to collaborate as they try to reach consensus on explanations for what they were trying to do, and descriptions of their results and conclusions.

Lastly, be sure to allow time—as much as a full period—for students to share their laboratory results with each other, and to relate these results with issues that they are learning about through reading materials. Points of disagreement might be resolved by further research by a small team of students composed of members on both sides of the issue—reflecting what actually occurs in the scientific community.

What to do about misconceptions

A common misconception is that “the hole in the ozone layer causes global warming.” If you hear students express such ideas, you can learn much more about their thinking (and be in a better position to help them) if you do not immediately tell them this is wrong, but instead ask them what they mean by their statement.

By asking students probing questions, you get them to think more deeply about their own understanding of the world. For example, one student explained that he thought the “hole in the ozone layer” was a physical hole in some sort of transparent membrane. Ozone, in his view, was literally a sheet of plastic that enclosed the whole Earth. When he expressed this idea, he realized that it didn’t sound entirely reasonable, and he was therefore open to the idea of the ozone layer as a concentration of a kind of gas, and the “hole” as an area where there was less gas than normal. It was necessary for this student to find

the problem with his previous understanding of the atmosphere—to unravel his misconception—before he could begin to understand what was meant by the metaphorical “hole” in the ozone “layer.”

In general, whenever you discover misconceptions, ask your students to clarify what they mean, and then ask other students if they agree or if they have some other idea. Once several students have expressed their opinions, try to summarize the different points of view, write these different ideas on butcher paper or on the chalkboard, and tell the students that you’ll get back to it later.

The next day, many students may have read the text more thoroughly and be able to point out misconceptions in the previous day’s discussion. In other cases, you will need to help them sort out fact from fiction. But however you do it, you will need to help your students identify and unravel their previous misconceptions, and not expect them to learn a new concept without reference to their previous understanding.

In Summary

This Teacher’s Guide is intended to be used as a resource rather than a prescription. Just as there is no “average” group of students, there is no ideal way to teach this course. You are encouraged to use what you find reasonable and useful in this Guide, and to invent your own methods for increasing student interaction.

Note: For those who would like to read more about the constructivist approach to teaching science discussed on this page, and the assessment methods described on the next few pages, one of the best current sources is the National Science Education Standards, available from the National Academy Press, 2101 Constitution Avenue, NW, Lockbox 285, Washington, DC 20055.

How Can I Assess Student Learning?

Assessment can be thought of as the collection of evidence to show whether or not students are achieving the objectives of the course. In deciding how to collect data it's useful to think of the different reasons for assessment. One is for **diagnostic** purposes, to find out what your students know before you start, so you can decide what to emphasize or how much time to spend on certain concepts. Another is to provide **feedback to students**. This is commonly called grading, though letter grades provide incomplete information to students on how well they are doing, and how they can improve. A third is to **evaluate your teaching**. By finding out how your students' ideas have changed during the course, you can figure out whether or not to review or to go on, or how to do a better job next year. In this section we'll consider these different uses one at a time.

Diagnosing student needs

An excellent strategy for beginning any science class is to first find out what your students already know about the topic you are about to teach. What do most students understand about this subject? What are their opinions? What misconceptions are common? Where should you start?

At the beginning of each part of the Teacher's Guide are a set of questions for assessing your students' understanding. You'll find that the suggested questions are open-ended. They are designed to elicit your students' knowledge, ideas, and opinions about the issues discussed in the unit to follow. Do not score their responses as "right" or "wrong," but instead, try to categorize responses in ways that help you recognize common viewpoints and attitudes, so you can plan accordingly. The same questions can be used after completing the unit, so that by comparing the pre- and post-tests of individuals, you can find out how your students' knowledge and attitudes changed during the unit.

You may also want to use the questionnaires as a springboard for discussion. First, collect the students' papers so that you can later compare their pre- and post-tests. Divide the class into small discussion groups of 3-4 students, and give each group a blank questionnaire. Ask them to try and agree on the best answers. After 15 or 20 minutes, have each group report its conclusions.

In a large group discussion, focus on one question at a time. Do not agree or disagree with the students at this point. Ideas will flow more freely once they realize that they cannot be "wrong." Encourage them to listen to each other and to change their minds if they think that other students' arguments are persuasive. Take notes during the large group discussion, and use these notes as a source of assessment data.

Providing feedback to students

Frequent, low-key feedback is probably more effective in changing students' behaviors, and helping them to become better learners, than the high stakes awarding of grades at the end of the semester. When grades are required (as they almost always are), they are far more meaningful if supplemented by a paragraph describing the student's strengths and areas in which he or she should improve. But such comments need to be based on data.

One approach is to collect information about desirable student behaviors during class. Create a checklist so that you can give students points for active participation in discussions, laboratories, and other in-class activities. Then use the checklist as a source of assessment data when it's time to provide feedback to students at the end of the quarter.

A very powerful method for providing feedback to students is to require that they maintain a portfolio of work they produce during the quarter. Involving each student in the process of selecting and improving work that goes into their portfolio, and articulating how a given piece of work demonstrates understanding of a key concept can be a very effective way to communicate the criteria for success, and encourage students to take responsibility for their own learning. On the next page are reports by two GSS teachers who have found portfolios to be especially helpful in providing feedback to students.

Process Folios

by **Cindy Moss, North Syracuse High School**
Syracuse, New York

For the last 2 years we have been using "process folios." The process folio is a folder we keep in the classroom that contains student work. The students are shown models of the types of work that receive various grades and are given help in determining what to place in their folios. Each Friday we spend approximately 15 minutes with folios allowing students time to select work to place inside. We named them "process folios" because we wanted to show a succession of work, not just the best work of each student. The students take regular objective tests and quizzes as well as essay exams. They also do labs, activities, graphic organizer assignments and homework. Each Friday a sample of any one of these assignments could go into their folio. These assignments have already been graded, but the student may choose to rewrite an assignment to improve a grade.

Each quarter the students have a major project. The major projects are: a children's book on ecology (1st quarter), researching and

participating in a job shadow (2nd quarter), researching and presenting a science fair project (3rd quarter), and preparing an advertisement for the human body (4th quarter). Progress reports from these projects go into their folios. The students also have five state required labs that must be placed in their folios. At the end of the quarter I meet with each student to discuss their work and evaluate their folio. At the end of the year we select their best work which includes a writing assignment, lab, homework, journal writing, and their quarter projects. These are put into the computer as a catalog for each student, and can be accessed by teachers in following years.

We have been pleasantly surprised by our results. We thought it would be much more difficult to do. The students are allowed time for self-assessment, peer assessment, and are given teacher assessments. They are much harder on themselves and their peers than the teachers are.

Portfolios...One Teachers' Experience

by Chad Husting, Bishop Fenwick High School

Middletown, Ohio

First, I defined a portfolio as a collection of work over time. Secondly, I clearly defined how I would grade the portfolios. Some people call this a "rubric!" My "rubric" was as follows:

- A Typed, evident that time was spent on it, creative, correctly used grammar. Evidence of outside research properly cited. Well-organized, raises questions, has applications.
- B. Some of it typed, Neat, organized, and suggests how to improve activity. Few mistakes.
- C Not typed. Organized and neat, but difficult to read. Reasoning is logical
- D. Illogical. Does not have all requirements, messy, not typed.

Next, I told the students what

had to be in their portfolios. It included:

- Five or six pieces of the student's best work, including art, essays, research, or suggestions for a better lesson. (Next time I may ask students to include their worst work, too.)
- The portfolio should include a table of contents with a brief summary of each work.
- The work cannot be all of the same kind.
- It must have at least one piece of written work and a review of a chapter not covered in the text.
- One portfolio piece can be done with other students, but they must be given credit for their contribution.

At the end of each week, I had students select work for their portfolios. If they received a "C" they could redo the work and get an "A" or "B." On Monday, I would show students examples of "A" work so that they would know what to look for. I liked doing portfolios and it was less work than I expected. I found that having a detailed rubric made grading simple. The best part of having portfolios was that if a student questioned their grade, all I had to do was pull out their portfolio!

Evaluating and modifying your program

By the end of a class in *Global Systems Science* students' skills, concepts, and attitudes should be different from when they started. They should not, however, all have the *same* ideas, if the course is taught as intended. An important aspect of scientific literacy is that students develop their *own* environmental ethic and make consistent choices for personal actions. To assess whether or not these outcomes have been achieved, multiple-choice tests have limited usefulness. Luckily, other tools are available.

First, there are the pre-post-tests that are included at the beginning of each part of the Teacher's Guide. Ask students to fill these out again, possibly using colored paper so there is no mistake about which papers are pre-tests and which are post-tests. Compare individuals' pre- and post-tests side by side to see how students have changed their knowledge, ideas, and attitudes.

The second source of data is student portfolios, if you choose to use these. Look for changes in the quality of student work over time.

The third source of data is the work that students are asked to produce at the end of each Student Guide. This generally includes a concept map, which shows the major concepts that the students identify and their understanding of how these concepts are related. It also includes an essay which invites students to pull together what they have learned. Feel free to modify the assignment and give guidelines about the length or procedure so it is appropriate for your students. Read the students' work to see if you can make some generalizations about how their thinking in this area may have improved as a result of this part of the course.

Understanding how your students' ideas have changed is the first major step in evaluating and

modifying your teaching. Was the course effective in changing students' understanding and perceptions? Did the course affect their attitudes and interests? Were there certain ideas or understandings that never changed? What about the course seemed to be most effective?

The next step is deciding what to do about it. How might you improve it next time? Which course materials will you continue to use, and which will you replace or modify? Which concepts need further reinforcement, and which should be skipped? What activities and teaching methods should be continued, and which need to be replaced? What seems to be the best use of in-class time, and what are the most effective kinds of homework assignments?

Evaluation can be made much easier and more effective if you are able to work with another teacher who might provide a fresh perspective. As a team you can look over student work and plan changes in the overall program.

Student Assessment at Wilton High

Jim Lucey and Tom Wellington have formed such a team at Wilton High School, in Wilton, Connecticut, where Tom has taught biology and environmental science, and Jim has taught physics and physical science. They were thinking about changing their high school program when they heard about the GSS Summer Institutes. They applied and both were accepted as a team. They now teach Global Systems Science and assist each other in evaluating and improving the course.

Recently, Tom responded to our request for sample pre- and post-test results, and also shared some papers from his students' portfolios. In his cover letter he wrote:

I can't tell you how well the GSS materials have fit into our constantly evolving curriculum in grade 10. We actually had need of this kind of material when Jim Lucey and I first heard of your project.... I'm really into the "Climate Change" module, and was anxious to run it again with the level-2 kids this year. This went well and was a focus of study for about 3 weeks, with suitable supplements and labs....

The student papers that Tom sent us were very revealing, showing what students learned from the course, and which misconceptions persisted. On the plus side was this set of student responses:

Question: How do you think knowledge of the way life and climate have interacted in the past might be of use today?

Pre-test answer: We could learn from them or compare them to today as sort of a goal for what we'd like to go back to.

Post-test answer (same student): I think we can learn from the past by looking at the good and bad things humans did back then and we can determine if all the earth's problems are man-made. Also by using information from the past we can tell if global warming has already begun.

This pair of responses reveals that the student learned a great deal about why scientists study past climates, although he is still somewhat unclear about the period of time when humans existed.

On the other hand, Tom was surprised to find that several students who started out with the misconception that the "hole" in the ozone layer causes global warming, still had the same misconception after they spent several weeks studying *Closing the Ozone Hole!* It's pretty clear that he will need to help the students unravel that misconception rather than just tell them it isn't so.

Following is a student paper from an activity in the *Changing Climate* module entitled "Discovering Evidence of Change." The purpose of the activity was to discover evidence of how people have changed the environment. Photos of an area taken at two different times, or interviews with older people were suggested as acceptable kinds of evidence. How would you evaluate the effectiveness of this activity for this student?

“Discovering Evidence of Change”

by Jason Petre

For this project I interviewed my father about Buffalo, New York. My parents are from Buffalo and I’ve visited many of my relatives who remain there today. From the year 1955 to the year 1995 many changes occurred in Buffalo which affected the Earth’s atmosphere.

In 1955 large steel plants were a common sight in Buffalo. Two of the largest plants were on the shore of Lake Erie west of Buffalo’s populated areas. The strong prevailing westerly winds would blow the pollution all over the city of Buffalo which had a population of about 1,000,000.

Newer modern steel making facilities built after World War II in other parts of the U.S. and in Germany and Japan forced Buffalo’s older inefficient mills to close down in the 1960s and 1970s. This produced massive loss of jobs. Now in 1996 the population of Buffalo is only 600,000 due to the loss of jobs. For the above stated reasons, the atmosphere in Buffalo is now much cleaner than it was in 1955.

Buffalo’s change over the last 40 years is an exception to the general rule. My father told me of a beautiful, small trout lake in the Adirondacks which was teeming with life in the 1950s. My father fished this lake an entire day in 1973 and the entire lake was lifeless. There were no frogs, no water insects, and no fish of any kind; even though the water was crystal clear in appearance. This lake was a victim of acid rain produced by an increasingly polluted atmosphere blown to the Adirondacks from Chicago, Detroit, Pittsburgh, and Cleveland.

As shown above, humans are changing the atmosphere. Studies show the general trend of increasingly polluted air over the last 140 years, with many harmful consequences as described above. Instead of being discouraged by the general trend, we must be encouraged by local successes such as Buffalo, which now has cleaner air.

At the end of each Student Book is an essay assignment you can modify and give guidelines that are appropriate for your students. Read the students’ work to see if you can make some generalizations about how your students’ thinking in this area may have improved as a result of the course.

How is GSS Related to Science Education Reform?

If the 1980s was the “decade of crisis” in science education, then the 1990s may well be the “decade of change.” Professional organizations consisting of scientists and teachers, with support from the National Science Foundation and other agencies, are challenging the status quo. In the past six years, several key documents have been produced which are redefining science education in the United States. Four of the most useful documents are as follows:

Science for All Americans, Project 2061, American Association for the Advancement of Science, Washington, D.C., 1989. This book describes what every American should know by the time they graduate from high school.

Scope, Sequence, and Coordination (SS&C), Vol. I The Content Core, National Science Teachers Association, Washington, D.C., 1992. The SS&C project calls for a new arrangement of the middle and high school curriculum, in which every student takes every science, every year. This book describes the SS&C approach and outlines key concepts that students should learn in grades 6-8, 9-10, and 11-12.

Benchmarks for Science Literacy, Project 2061, American Association for the Advancement of Science, Washington, D.C., 1993. The Project 2061 staff published these guidelines for what students should learn about science during grade levels K-2, 3-5, 6-8, and 9-12.

National Science Education Standards Draft, National Research Council of the National Academy of Sciences, Washington, D.C., December, 1995. The *National Standards* proposes sweeping changes in the science education system, projects a vision of good teaching practices, guidelines for assessing student learning, and provides its own list of key concepts that all Americans should learn in grades K-4, 5-8, and 9-12.

Although each of these documents focuses on different aspects of the education system, they all offer a similar image of the ideal science classroom as a place where students are actively engaged in inquiry. They all recognize that students enter the classroom with certain information about the world, and that they construct their own meanings from these preconceptions, as well as what they see, hear, and do in school. All identify similar lists of the most important scientific concepts, theories, and attitudes that should form the core

of the school science curriculum. All emphasize the need to teach fewer topics in greater depth, and to teach not only what scientists have learned about the world, but how they have learned it. And all of them suggest that high school science courses might be more useful and appealing to students if they focus on interdisciplinary issues relevant to our modern world instead of the disciplines of biology, chemistry, and physics. The *Global Systems Science* course was developed in response to these principles.

Teaching About Global Environmental Change

Also relevant to the Global Systems Science program is that each of the reform documents specifically addresses the importance of teaching students about global environmental change. Following are a selection of quotes that address major topics included in the *Global Systems Science* course.

The concept of Earth systems. *The idea of systems provides a framework in which students can investigate the four major interacting components of the Earth system—geosphere (crust and the interior), hydrosphere (water), atmosphere (air), and the biosphere (the realm of all living things.) In this holistic approach to studying the planet, physical, chemical and biological processes act within and between these four components on a wide range of time scales to continually change Earth’s crust, oceans, atmosphere, and living organisms.*

— National Standards Draft, page V-87.

Global warming and the “greenhouse effect.” *The teacher might lead a discussion or schedule activities about the “greenhouse effect.” Some evidence suggests that the combustion of fossil fuels—the principal process by which electricity is generated—could lead to an increase in the total amount of greenhouse gases in the atmosphere. The increased amount of greenhouse gases could lead, in turn, to global climatic changes (warming). Global warming could accelerate glacier and polar ice cap melting and cause a subsequent rise in sea level. The higher sea level could result in greater coastal erosion and the flooding of low-lying coastal areas (in which a large number of people live). The teacher should stress that this chain of events has not been proven to have occurred nor to be occurring. The current data is simply too limited and too complex for scientists to make a definitive statement.*

— SS&C, Volume I The Content Core, pages 86-87.

Loss of biodiversity. *The human species has a major impact on other species in many ways: reducing the amount of the earth’s surface available to those other species, interfering with their food sources, changing the temperature and chemical composition of their habitats, introducing foreign species into their ecosystems, and altering organisms directly through selective breeding and genetic engineering.*

— Benchmarks for Science Literacy, page 57.

Changing ecosystems. *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 is threatening global stability, and if not addressed, ecosystems will be irreversibly damaged.*

— National Science Education Standards Draft, page V-145.

The impact of human population growth. *The Earth does not have infinite resources, and increasing human production and consumption places severe stress on the natural processes that renew some resources and depletes those resources that cannot be renewed.*

— National Science Education Standards Draft, page V-162.

Teaching Fundamental Science Concepts

The reform documents purport to identify *all* of the most important concepts and theories that high school students should learn. Many of these key concepts and theories underlie the science of global environmental change, so they are presented in some detail in the GSS course materials. For example, the following quote from the National Standards Draft shows how fundamental concepts in geology, evolution, and climatology can be brought to bear on today's issues of global environmental change. This quote neatly summarizes key objectives of the GSS unit *Life and Climate*.

The co-evolution of life and climate. *In studying the evolution of the Earth system over geologic time, students develop a deeper understanding of the evidence, first introduced in grades 5-8, of Earth's past and unravel the interconnected story of Earth's dynamic crust, fluctuating climate, and evolving life forms. The students' studies develop the concept of the Earth system existing in a state of dynamic equilibrium. They will discover that while certain properties of the Earth system may fluctuate on short or long time scales, the Earth system will generally stay within a certain narrow range for millions of years. This long-term stability can be understood through the working of planetary geochemical cycles, and the feedback processes that help to maintain or modify those cycles. As an example of this long-term stability, students find that the geologic record suggests that the global temperature has fluctuated within a relatively narrow range, one that is narrow enough to enable life to survive and evolve for over three billion years. They come to understand that some of these small 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.*

— National Science Standards, page V-148, 149.

Getting Started

If you've made it to this page of the Teacher's Guide, you have already started the implementation process. The next step is to find a niche for Global Systems Science at your school. Several alternatives are discussed in "How Can I Customize GSS for My Students?" on pages 13-15. If you choose to start by implementing a one or two semester course in *Global Systems Science*, you will probably need approval. In districts where the top-down approach is preferred, talk with the Superintendent, Principal, or Science Coordinator as soon as possible. In districts where teams of teachers have taken the lead, you'll want to meet with the curriculum committee, or just start talking informally with other teachers. In still other districts, where change is likely to be very difficult, you may want to request budget

approval to order a class set of just one of the GSS Student Guides to enrich your chemistry, physics, Earth science, or biology course.

Getting Funding

Whatever approach you take to integrating *Global Systems Science* into your school, some funds will be necessary to purchase class sets of the Student Guides and laboratory supplies and equipment. Most of the equipment that will be needed is commonly available in science labs, or easily obtained from local sources; but some funds will certainly be needed to support the lab activities. School districts generally budget funds for lab supplies, new textbooks, and "enrichment" materials, so this is one possible source. Another source is donations from local companies.

Getting Your Feet Wet

Most of us on the GSS staff are former high school teachers. It's our impression that most high school teachers understand the nature of science, and the important theories, concepts, and techniques of one or two scientific disciplines. Consequently, it will probably not be too difficult for you to do a good job of teaching Global Systems Science, provided you have time to read through the Teacher's Guide and try out the experiments and activities in advance.

Is a Professional Development Program Necessary?

If *Global Systems Science* takes off at your school, and other teachers become involved, you will eventually be asked if a professional development program is necessary. The answer is a definite "No!" and an enthusiastic "Yes!" No, it is not *necessary* for teachers to undergo an expensive training program in order to use the GSS materials; but on the other hand, opportunities for teachers to improve their knowledge and capabilities will certainly improve the quality of the experience for students. This suggests a two-step strategy. First, get your feet wet by using some of the GSS materials with students. Then, as your efforts expand and other teachers become involved, set up a program that gives you the time you will need to work together with them, and help each other improve the course for students.

Articulating Needs for Staff Development

A little personal reflection may help to illustrate this point. Each of us on the staff of the GSS project considers ourselves to be "innovative" teachers; so we were quite surprised to find out how much we needed to learn when we switched from discipline-based teaching to an interdisciplinary course. Our need to devise new lessons would take us to unfamiliar territories in libraries and bookstores. In many cases, we had to switch from physics to biology as we went from one chapter to the next, or from science to economics and politics, so that we could follow up the implications of an issue instead of going on to "cover" the next science topic. Working together helped immensely, since our team had experience teaching all of the sciences plus social studies and mathematics; but we each had to learn a great deal as well about each others' fields, and about how to involve students in thinking deeply about social and ethical issues.

Professional Development Strategies

Once your *Global System Science* program is underway, you will probably be able to articulate specific needs for professional development. Seasoned teachers tell us that the best time for starting new collaborations and programs is in the summer, when the daily demands of teaching do not intrude on the need to think, read, try out new experiments, and plan together. Unless you and your colleagues are independently wealthy, you will want to approach your administrators to ask for funds that have been reserved for staff development in your district. Alternatively, you may want to write a grant proposal for state funding, or to a corporation in your community.

Following are some of the professional development activities that may meet some of your needs, beginning with those that will probably be easiest to implement:

- **Summer Institute.** An institute of 1-4 weeks provides an intensive period of time for experienced teachers and new teachers to work together, to be involved in hands-on activities, and to share strategies for teaching and student assessment.
- **Peer coaching.** Agree to work with a colleague, possibly in a different field of science, or in social studies or mathematics, to assist each other. You may develop and teach a course together, or visit each others' classes providing helpful suggestions and helping each other solve problems.

- **Mentoring.** A more experienced veteran can take a new teacher under his or her wing, helping the new teacher plan lessons, develop new techniques, gather materials, and solve problems. Mentoring activities can take place entirely at school, or in other educational settings such as universities and museums.
- **Team Teaching.** Form a group of teachers who will work together to develop a single course, or develop complementary courses for the same group of students. This could involve teachers from more than one department at your school. Time will be needed—either before or after school, on weekends, or staff development days, when you will all be free. Decide on common goals, strategies, and methods for assessing students learning, so you will know if you have been successful.
- **Teacher as Researcher.** As you and your colleagues become more comfortable with integrated science teaching you may want to conduct a more formal research study of student learning. For example, students’ pre-post-test results can be categorized and analyzed to specify what students typically know at the beginning of a course and how their knowledge and opinions change after instruction. If you do not feel entirely comfortable with educational research techniques, you may want to contact a graduate school of education for assistance and collaboration.
- **Teacher as Curriculum Developer.** If you encounter difficulties in teaching certain concepts, or if you see opportunities to relate one of the concepts presented in the GSS unit to a local resource, then you are ready to undertake curriculum development. The development of new activities does not need to take a great deal of time, and can be a magnificent learning experience in itself. If you do develop activities related to GSS, please share them with others, either through publications in teacher’s journals, by presentation at local, state, or national conferences, or by sending them to GSS Headquarters at the Lawrence Hall of Science!

When choosing professional development activities think about meeting your own needs—not just to increase your knowledge base and teaching capabilities, but to give free rein to your creativity, and to experience the exhilaration of learning new things. It’s a good bet that your students will sense your enthusiasm, and enjoy sharing your newest insights.

One final thought is that implementing a new program is not easy. Michael Fullan and Suzanne Stiegelbauer’s book, *The New Meaning of Educational Change* (1991) analyzes hundreds of studies of educational change, and offers a variety of insights. Among these is the importance of sharing your vision with others—with fellow teachers, parents, students, and most certainly with administrators. Without their support it’s difficult to implement anything new. With their support, implementation of a new program can be an exciting and rewarding experience that energizes the entire school community.

How Was GSS Created?

The driving force for new interdisciplinary courses came from the science education reform movement that has been gathering momentum in the early 1990s. But until recently, few materials had been published to help teachers break out of the traditional mold. Consequently, many teachers were asked to spend their summer months “writing a new course on global change.” The thought of thousands of teachers around the country laboring in isolation to create their own courses, when they had so much to learn from each other, gave rise to *Global Systems Science (GSS)* –a course created by the collaboration of teachers, scientists, and experienced curriculum developers at the Lawrence Hall of Science in Berkeley.

Development of the GSS materials started in 1990, when we were awarded a grant from the National Institute for Global Environmental Change (NIGEC), with funds from the U.S. Department of Energy, to develop a preliminary version of a high school course. But *Global Systems Science* would never have become a stimulating and informative course for students were it not for the creative and critical efforts of more than 150 teachers who worked on it between 1991 and 1995.

We started by sending preliminary drafts of the Student Guides and laboratory activities to teachers for their review. Later on we were awarded a grant from the National Science Foundation to provide provided full classroom sets of the Student Books so that teachers could try them with their students, then come to Berkeley for three weeks to provide feedback and create new activities. Other teachers, who were not able to come to Berkeley, tested the units with their students and sent us their feedback in the mail. We are indebted to all of these teachers and their students for helping to make *Global Systems Science* both interesting and practical for classroom use.

The fate of our first Student Book illustrates the important formative role played by teachers. GSS Volume 1, weighing in at 134 pages, was intended to be the first of five books in the GSS series. It was reviewed by 25 teachers, parents, students, and administrators, then revised before being sent out to another 25 teachers for testing with their students.

When the trial test teachers came to Berkeley, we received the news: On the plus side, the students really enjoyed learning about something that was really important—how humans may be affecting the climate of our entire planet. The material was readable and the students enjoyed most of the illustrations and all of the activities. On the other hand, the teachers recommended the following changes:

- **Change the title.** The original title, *A Planet Under Siege*, seemed to tell the students what to think. The whole topic of global warming and the greenhouse effect is controversial and we wanted the students to make up their own minds about it. Some scientists even predict

that we are entering another ice age. We modified the title to the more neutral phrase, *Changing Climate*.

- **Shorten the books.** The teachers strongly preferred shorter books that they could use in any order they chose. So, we changed the concept of the series from five volumes to be used consecutively, to nine short Student Guides, each under 100 pages, that could be used in any order.
- **Put most of the activities into the Teacher’s Guide.** Although text materials are important, the most vivid and meaningful way to communicate concepts to students is through activities, including laboratory experiments, simulations, games, and role play scenarios. Each Student Guide includes at least two laboratory activities, and the Teacher’s Guide includes ideas for many others.

- **Do not include a glossary.** There was considerable debate about this during every GSS Summer Institute. Glossaries seemed to emphasize memorizing the definitions of words over conceptual understanding. On the other hand, it seemed necessary to use certain words that we could not assume students already knew. We compromised by embedding definitions in the text, and highlighting these in *italics*, so that students would know that they were definitions.
- **Do not include questions at the ends of the chapters.** This issue was also hotly debated during the Summer Institutes. A problem with questions in the text is that some students skim through the material to answer the questions, rather than trying to grasp the big picture. Yet in certain places, questions are valuable to get the students to think about what they are reading. So, we embedded some questions in the text, highlighting these in *italics*, and included other questions in the Teacher's Guide.

These are just a few of the hundreds of individual changes recommended by teachers. Even more important are the many ideas for activities, assessment tasks, and resource materials that have become integral parts of the GSS program.

Scientists were involved in the development of the materials at several levels. Discussions with scientists (such as Arthur Rosenfeld at the Lawrence Berkeley National Laboratory, Stephen Schneider, now a professor in the Department of Biological Sciences at Stanford University, and Vic Mayer, Professor of Science Education, Geology, and Natural Resources at Ohio State University) helped to formulate the basic principles behind the GSS course in its early stages. Writings by scientists helped us map out the territory of *Global Systems Science* Student Guides, and write the first drafts of the course. Interviews with scientists provided valuable information about their research, as well as information about scientists and technicians as role models. Several scientists presented talks and conducted tours of their laboratories during the GSS Summer Institutes, leading to new activities by the institute participants. Scientists also reviewed the trial editions of the Student Guides, providing a check on the accuracy of the materials.

And finally, the full-time curriculum developers on the staff brought to the project decades of experience in formulating, testing, and revising educational materials that stimulate students' interests and that really work in the classroom. All of the curriculum developers, teachers, and scientists who worked on the project are acknowledged on the following pages.

Unlike some areas of science, such as classical physics, which are widely accepted by virtually all scientists, the results and conclusions of global systems science are constantly changing as new research studies resolve burning issues and raise new questions. The course materials must change in response to these new developments if it is to stay current; so, stay tuned for updates!

Additionally, we are open to suggestions from teachers about new activities and teaching methods. If you have suggestions for improving the GSS course materials, please send them to: Global Systems Science, Lawrence Hall of Science, University of California, Berkeley, CA 94720-5200. We look forward to hearing from you!

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