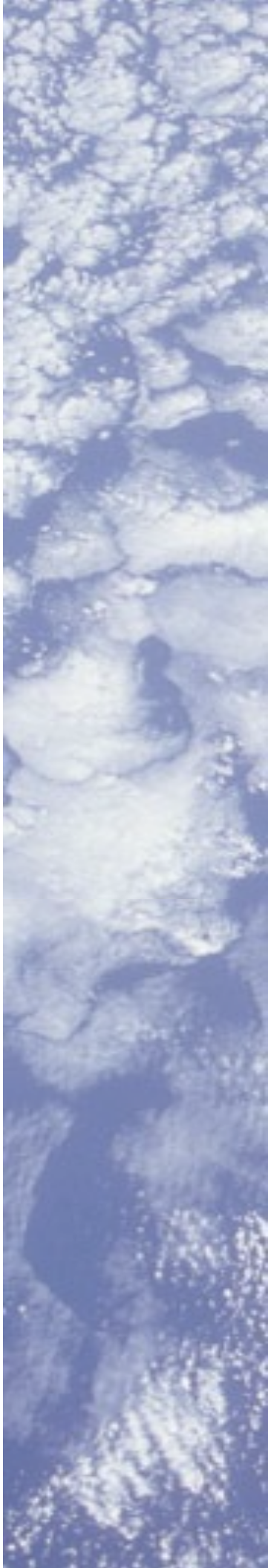
APPENDIX A

*Ed*GCM: In Step With National Education Standards

From its inception, the *Ed*GCM project has been proactive in ensuring that its educational goals, objectives and science-research activities are in concert with a large number of national educational standards that have been developed by organizations such as the National Research Council (National Science Education Standards); the American Association for the Advancement of Science (AAAS Project 2061 Benchmarks); the International Society for Technology in Education (National Educational Technology Standards for Students); and the National Council for Geographic Education (National Geography Standards for Students).

A series of correlations of national standards to *Ed*GCM research activities, which follows, illustrates the wide-ranging congruity of the *Ed*GCM program to these standards.



A.1 *Ed*GCM Correlations to National Science Education Standards – Science Content Standards (High School)

CONTENT STANDARD A:	*EdGCM ACTIVITIES IN SUPPORT OF CONTENT STANDARD A:*
As a result of activities in grades 9-12, all students should develop understanding of • Abilities necessary to do scientific inquiry • Understandings about scientific inquiry	• Students actively participate in scientific investigations, and use the cognitive and manipulative skills associated with the formulation of scientific explanations. • EdGCM investigations are meaningful to students. They are derived from current questions and issues that impact the lives of all people around the globe. • Students use computers for the analysis and display of data in a variety of formats. • Students formulate and revise scientific explanations and models using logic and evidence

CONTENT STANDARD B:	*AS A RESULT OF EdGCM ACTIVITIES STUDENTS SHOULD DEVELOP THESE UNDERSTANDINGS OUTLINED IN CONTENT STANDARD B:*
As a result of their activities in grades 9-12, all students should develop understanding of • Structure and properties of matter • Motions and forces • Chemical reactions • Conservation of energy and increase in disorder • Interactions of energy and matter	• Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog. • In some chemical reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.

CONTENT STANDARD C:

As a result of their activities in grades 9-12, all students should develop understanding characteristics of

- The cell

- Matter, energy, and organization in living systems

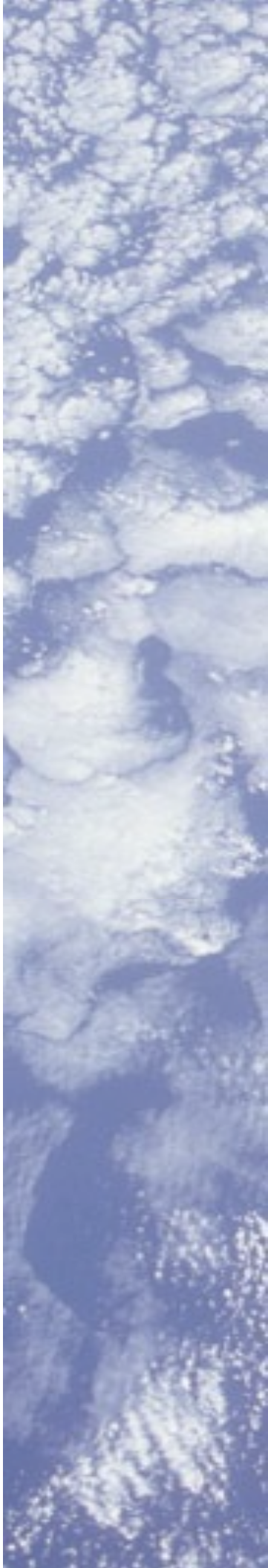
- Behavior of organisms

AS A RESULT OF EdGCM ACTIVITIES STUDENTS SHOULD DEVELOP THESE UNDERSTANDINGS OUTLINED IN CONTENT STANDARD C:

- Plant cells contain chloroplasts, the site of photo-synthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.

- As matter and energy flows through different levels of organization of living systems—cells, organs, organisms, communities—and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

- Organisms have behavioral responses to internal changes and to external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes; these responses either can be innate or learned. The broad patterns of behavior exhibited by animals have evolved to ensure reproductive success. Animals often live in unpredictable environments, and so their behavior must be flexible enough to deal with uncertainty and change. Plants also respond to stimuli.



CONTENT STANDARD D:

As a result of their activities in grades 9-12, all students should develop understanding of

- Energy in the earth system
- Geochemical cycles
- Origin and evolution of the earth system

In conducting climate research, students develop a deeper understanding of the evidence of earth's past and unravel the interconnected story of earth's fluctuating climate. The students' studies develop the concept of the earth system existing in a state of dynamic equilibrium. They discover that while certain properties of the earth system may vary 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 has been narrow enough to enable life to survive and evolve for over three billion years. They come to understand that some of the 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.

AS A RESULT OF EdGCM ACTIVITIES STUDENTS SHOULD DEVELOP THESE UNDERSTANDINGS OUTLINED IN CONTENT STANDARD D:

Energy in the earth system

- Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from the earth's original formation.
- Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents.
- Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans.

Geochemical cycles

- The earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical reservoirs. Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.
- Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.

The origin and evolution of the earth system

- Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations. Current methods include using the known decay rates.

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CONTENT STANDARD G:

As a result of activities in grades 9-12 , all students should develop understanding of

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

AS A RESULT OF EdGCM ACTIVITIES STUDENTS SHOULD DEVELOP THESE UNDERSTANDINGS OUTLINED IN CONTENT STANDARD G:

• Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.

• Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirma-tions and are therefore unlikely to change in the areas in which they have been tested. In areas where data or under-standing 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 where information is still fragmentary, it is normal for scientific ideas to be incom-plete, but this is also where the opportunity for making advances may be greatest.

• The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge.

A.2 *Ed*GCM Correlations to National Science Education Standards – Science Teaching Standards (High School)

TEACHING STANDARD B:

- Teachers of science guide and facilitate learning. In doing this, teachers

- Focus and support inquiries while interacting with students.

- Orchestrate discourse among students about scientific ideas.

- Challenge students to accept and share responsibility for their own learning.

- Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

EdGCM ACTIVITIES IN SUPPORT OF STANDARD B:

- *Ed*GCM research activities are inquiry-based. Students are encouraged to interact and exchange ideas with each other, their teacher, and with research scientists during the course of their investigations.

- Teachers introduce the functions of the *Ed*GCM application; explain the use of climate models in climate research; and describe the process by which scientists evaluate their conclusions and submit their research to peer review.

TEACHING STANDARD D:

- Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. In doing this, teachers

- Structure the time available so that students are able to engage in extended investigations.

- Make the available science tools, materials, media, and technological resources accessible to students.

- Identify and use resources outside the school.

EdGCM ACTIVITIES IN SUPPORT OF STANDARD D:

- *Ed*GCM activities can be conducted for various periods of time, including extended research.

- The *Ed*GCM software application, a fully operational desktop version of a global climate model, is a unique resource that enables students to conduct genuine research activities in collaboration with research scientists and educators in colleges and universities.

TEACHING STANDARD E:

• Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.

• In doing this, teachers and their colleagues

• Nurture collaboration among students.

• Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.

• Model and emphasize the skills, attitudes, and values of scientific inquiry.

EdGCM ACTIVITIES IN SUPPORT OF STANDARD E:

• The research activities of EdGCM may be carried out by groups of students in a collaborative effort, with each pupil assigned specific tasks within the research framework.

• Research tasks assigned to groups of students require that a continuing exchange of ideas and results be communicated in a scientifically appropriate manner.

• In order to ensure that EdGCM student research is properly planned and conducted, teachers stress the skills, attitudes and values of scientific inquiry.

LESS EMPHASIS ON

Treating all students alike and responding to the group as a whole.

Rigidly following curriculum

Focusing on student acquisition of information

Presenting scientific knowledge through lecture, text, and demonstration

Asking for recitation of acquired knowledge

Testing students for factual information at the
end of the unit or chapter

Maintaining responsibility and authority

Supporting competition

Working alone

MORE EMPHASIS ON

Understanding and responding to individual student's interests, strengths, experiences, and needs

Selecting and adapting curriculum

Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes

Guiding students in active and extended scientific inquiry

Providing opportunities for scientific discussion and debate among students

Continuously assessing student understanding

Sharing responsibility for learning with students

Supporting a classroom community with cooperation, shared responsibility, and respect

Working with other teachers to enhance the science program

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A.3 *Ed*GCM Correlations to AAAS Project 2061 Benchmarks – Science Content Standards (High School)

1. THE NATURE OF SCIENCE **A. The Scientific World View**

Aspects of the scientific world view can be illustrated in the upper grades both by the study of historical episodes in science and by reflecting on developments in current science. Case studies provide opportunities to examine such matters as the theoretical and practical limitations of science, the differences in the character of the knowledge the different sciences generate, and the tension between the certainty of accepted science and the breakthroughs that upset this certainty.

• From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge. Change and continuity are persistent features of science.

• No matter how well one theory fits observations, a new theory might fit them just as well or better, or might fit a wider range of observations. In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to an increasingly better under-standing of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK A:

• Students actively participate in scientific inquiry, and use the cognitive and manipulative skills associated with the formulation of scientific explanations.

• *Ed*GCM research investigations are meaningful to students. They are derived from current questions and issues that impact the lives of all people around the globe.

• Students formulate and revise scientific explanations and models using logic and evidence derived from *Ed*GCM climate model data and analysis.

1. THE NATURE OF SCIENCE **B. Scientific Inquiry**

Students' ability to deal with abstractions and hypothetical cases improves in high school. Now the unfinished and tentative nature of science may make some sense to them. Students should not be allowed to conclude, however, that the mutability of

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK B:

The *Ed*GCM research experience involves students in the following science inquiry activities:

• Formulating a hypothesis

• Selecting variables to be tested

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science permits any belief about the world to be considered as good as any other belief. Theories compete for acceptance, but the only serious competitors are those theories that are backed by valid evidence and logical arguments.

The nature and importance of prediction in science can also be taken up at this level. Coverage of this topic should emphasize the use of statistics, probability, and modeling in making scientific predictions about complex phenomena often found in biological, meteorological, and social systems. Care also should be taken to dissociate the study of scientific prediction from the general public's notions about astrology and guessing the outcomes of sports events.

By the end of the 12th grade, students should know that:

• Investigations are conducted for different reasons, including exploring new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.

• Hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of the data (both new and previously available).

• Sometimes, scientists can control conditions in order to obtain evidence. When that is not possible for practical or ethical reasons, they try to observe as wide a range of natural occurrences as possible to be able to discern patterns.

• There are different traditions in science about what is investigated and how, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments.

• And there is agreement that progress in all fields of science depends on intelligence, hard work, imagination, and even chance.

• Running authentic climate simulations

• Revising and reformulating a hypothesis

• Running a revised climate simulation, when required

• Analyzing climate simulation data

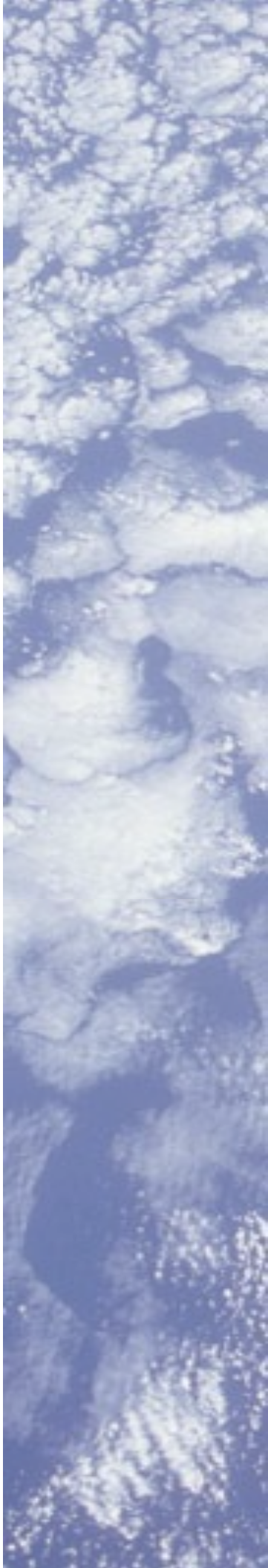
• Drawing conclusions from these data

• Developing explanations for past climates

• Predicting future climate trends

• Collaborating with classmates, students from other schools and universities, and research scientists

• Publishing and sharing the results of research via the Internet



• Scientists in any one research group tend to see things alike, so even groups of scientists may have trouble being entirely objective about their methods and findings. For that reason, scientific teams are expected to seek out the possible sources of bias in the design of their investigations and in their data analysis. Checking each other's results and explanations helps, but that is no guarantee against bias.

• In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. In the long run, theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings.

• New ideas in science are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many investigators.

1. THE NATURE OF SCIENCE
C. The Scientific Enterprise

No matter how the curriculum is organized, it should provide students with opportunities to become aware of the great range of scientific disciplines that exist. There is no sense, however, in having students memorize definitions of anthropology, astrophysics, biochemistry, paleobacteriology, and the rest of the family. Individual students or small groups of students can study different disciplines in some detail—most scientific societies are happy to help out—and then share their findings with one another. The focus of such studies should be substantive (what are typical studies like in the discipline) and sociological (how is the field organized and who is in it), and they should probably involve, over an extended time, interviews, field trips, readings, data analysis, and, if possible, the conduct of small-scale experiments or field studies. Such activities will contribute to science literacy goals, and they should also help

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK C:

• The *Ed*GCM research experience may often involve students in projects that could require appropriate simultaneous studies within the Earth System, biological, environmental, and chemical sciences in collaboration with groups of students in other schools, university faculty, and research scientists.

• As a result of their experiences, students will become knowledgeable about the inter-disciplinary nature of climate research.

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students realize how many different career possibilities exist in science.

• Science disciplines differ from one another in what is studied, techniques used, and outcomes sought, but they share a common purpose and philosophy, and all are part of the same scientific enterprise. Although each discipline provides a conceptual structure for organizing and pursuing knowledge, many problems are studied by scientists using information and skills from many disciplines. Disciplines do not have fixed boundaries, and it happens that new scientific disciplines are being formed where existing ones meet and that some subdisciplines spin off to become new disciplines in their own right.

4. *THE PHYSICAL SETTING*
B. The Earth

By the end of the 12th grade, students should know that

• Life is adapted to conditions on the earth, including the force of gravity that enables the planet to retain an adequate atmosphere, and an intensity of radiation from the sun that allows water to cycle between liquid and vapor.

• Weather (in the short run) and climate (in the long run) involve the transfer of energy in and out of the atmosphere. Solar radiation heats the land masses, oceans, and air. Transfer of heat energy at the boundaries between the atmosphere, the land masses, and the oceans results in layers of different temperatures and densities in both the ocean and atmosphere.

• The action of gravitational force on regions of different densities causes them to rise or fall—and such circulation, influenced by the rotation of the earth, produces winds and ocean currents.

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK B:

*Ed*GCM research activities enable students to acquire a thorough knowledge of:

• the hydrologic cycle

• the transfer of solar radiation at and near the earth's surface

• the influence of dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans on the transfer of solar energy

• the heating of earth's surface and atmosphere by the sun in driving convection within the atmosphere and oceans, producing winds and ocean currents

• the interactions among the solid earth, the oceans, the atmosphere, and organisms that have resulted in the ongoing evolution of the earth system

E. Energy Transformations

Two major ideas merit introduction during these years, but without resort to mathematics. One of these is that the total amount of energy available for useful transformation is almost always decreasing; the other is that energy changes on the atomic scale occur only in discrete jumps. The first of those is not too difficult or implausible for students because they can experience in many ways a wide variety of actions that give off heat. The emphasis should probably be on the practical consequences of the loss of useful energy through heat dissipation.

By the end of the 12th grade, students should know that

• Whenever the amount of energy in one place or form diminishes, the amount in other places or forms increases by the same amount.

• Heat energy in a material consists of the disordered motions of its atoms or molecules. In any inter-actions of atoms or molecules, the statistical odds are that they will end up with less order than they began—that is, with the heat energy spread out more evenly. With huge numbers of atoms and molecules, the greater disorder is almost certain.

• Transformations of energy usually produce some energy in the form of heat, which spreads around by radiation or conduction into cooler places. Although just as much total energy remains, its being spread out more evenly means less can be done with it.

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK E:

• Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New tech-nologies often extend the current levels of scientific understanding and introduce new areas of research.

• Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations.

• Many scientific investigations require the contributions of individuals from different disciplines, including engineering.

• New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines

12. HABITS OF MIND
B. Computation and Estimation

Where do calculators and computers come into the picture? The answer is, nearly everywhere. And computers, with their easy-to-use spreadsheet, graphing, and database capabili-ties, have become tools that everyone can use, at home and at work, to carry out extensive quantitative tasks.

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK B:

*Ed*GCM research activities enable students to:

• create computer spreadsheets, graphs, and tables to assist in quantitative data analysis

• graphically compare data and analyses

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By the end of the 12th grade, students should be able to

• Use computer spreadsheet, graphing, and database programs to assist in quantitative analysis.

• Compare data for two groups by representing their averages and spreads graphically.

D. Communication Skills

Good communication is a two-way street. It is as important to receive information as to disseminate it, to understand other's ideas as to have one's own understood. In the scientific professions, tradition places a high priority on accurate communication, and there are mechanisms, such as refereed journals and scientific meetings, to facilitate the sharing of new information and ideas within various disciplines and subdisciplines. Science-literate adults share this respect for clear, accurate communication, and they possess many of the communication skills characteristic of the scientific enterprise.

By the end of the 12th grade, students should be able to

• Write clear, step-by-step instructions for conducting investigations, operating something, or following a procedure.

• Choose appropriate summary statistics to describe group differences, always indicating the spread of the data as well as the data's central tendencies.

• Use and correctly interpret relational terms such as if . . . then . . . , and, or, sufficient, necessary, some, every, not, correlates with, and causes.

• Participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarification or elaboration, and expressing alternative positions.

• Use tables, charts, and graphs in making arguments and claims in oral and written presentations of data

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK D:

*Ed*GCM encourages students to:

• join in on-line group discussions about their research activities with other students, undergraduate faculty/students, and research scientists

• create and publish Internet-based research papers and reports either independently or in collaboration with students in other schools, undergraduate faculty/students and/or research scientists

*Ed*GCM activities require that students:

• Use tables, charts, and/or graphs in making arguments and claims in oral and written presentations regarding their research findings

A.4 *Ed*GCM Correlations to International Society for Technology in Education (ISTE) National Educational Technology Standards for Students (High School)

ISTE Standards for High School Students	*EdGCM Activities in Support of ISTE Standards:*
Routinely and efficiently use online information resources to meet needs for collaboration, research, publications, communications, and productivity. (4, 5, 6)	Students routinely use the on-line Forum, eJournal, SimExchange (simulation exchange) and web publishing components for communi-cations, collaborative research, and publishing of results.
Select and apply technology tools for research, information analysis, problem solving, and decision-making in content learning. (4, 5)	The *Ed*GCM global climate model (GCM) provides students with an opportunity to be engaged in genuine scientific research that requires hypothesis development, experiment design, running simulations, visualization, analysis and interpretation of data, and reporting results. These processes assist students in solving real scientific problems.
Investigate and apply expert systems, intelligent agents, and simulations in real-world situations. (3, 5, 6)	*Ed*GCM allows students to simulate past, present, and future climates using an actual NASA/GISS GCM.
Collaborate with peers, experts, and others to contribute to a content-related knowledge base by using technology to compile, synthesize, produce, and disseminate information, models, and other creative works. (4, 5, 6)	*Ed*GCM fosters collaborations between precollege educators, students, university faculty, and the research community. These partnerships are accomplished through the ongoing utilization of the on-line components cited above.

Numbers in parentheses following each performance indicator refer to the standards category to which the performance is linked. The categories are:

3. Technology productivity tools
4. Technology communications tools
5. Technology research tools
6. Technology problem-solving and decision-making tools

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A.5 *Ed*GCM Correlations to the National Council for Geographic Education (NCGE) – National Geography Standards for Students (Grades 9 - 12)

NCGE Standards for Students Grades 9-12	*EdGCM Activities in Support of NCGE Standards:*
STANDARD 1: How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information.	• *Ed*GCM provides students with the tools to create computer-generated maps of atmospheric and oceanic variables, plotted in a variety of projections and regions, which they analyze and interpret in order to draw conclusions regarding their research studies.
STANDARD 4: The physical and human characteristics of places.	• During the course of their research, *Ed*GCM student-participants are often required to compare and contrast numerous characteristics of the Earth's surface and its environment.
STANDARD 5: That people create regions to interpret Earth's complexity.	• Student research can also be required to draw conclusions regarding human actions, processes, population characteristics, patterns, and migrations as they relate to specific investigation topics and results.
STANDARD 7: The physical processes that shape the patterns of Earth's surface.	• During the course of numerous climate research studies, students will define the interactions between climate, continental distribution, and topography in the past and present.
STANDARD 8: The characteristics and spatial distribution of ecosystems on Earth's surface.	
STANDARD 9: The characteristics, distribution, and migration of human populations on Earth's surface.	
STANDARD 12: The process, patterns, and functions of human settlement.	
STANDARD 14: How human actions modify the physical environment.	
STANDARD 16: The changes that occur in the meaning, use, distribution, and importance of resources.	
STANDARD 17: How to apply geography to interpret the past.	
STANDARD 18: To apply geography to interpret the present and plan for the future.	