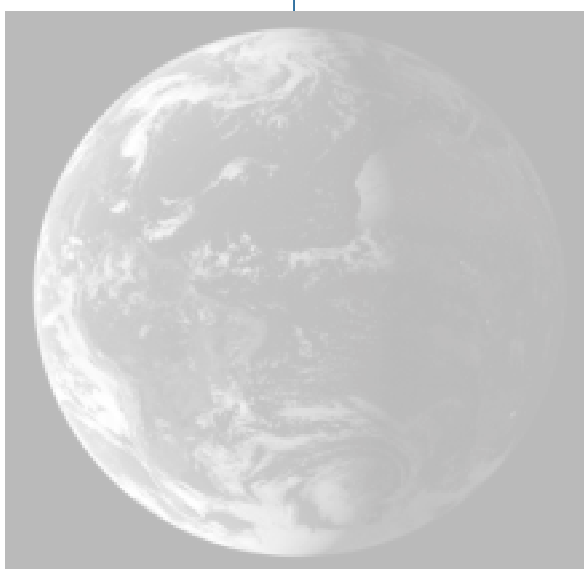
Blueprint for Change: Report from the National Conference on the

Revolution

in Earth and Space Science Education



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For copies of the report in PDF format or for more information on the revolution in Earth and space science education, visit the Web site:

www.EarthScienceEdRevolution.org

Acknowledgments

The conveners would like to express our appreciation to NSF Program Officers Mike Mayhew and Dottie Stout for their support of this project. This workshop would not have been possible without the energy, enthusiasm and ideas of the organizing committee and the working group facilitators who contributed substantially to the preparation of this report. Finally, we would like to thank our outstanding workshop participants, whose vision, dedication, and expertise have helped us to launch this Revolution in Earth and Space Science Education. Editing and compilation of the working group reports and recommendations were done by Harvey Yazijian. Layout, design and production were done by Sandy Schafer.

This "Blueprint for Change" report is dedicated to the memory of Dorothy Lalonde Stout, colleague, friend and catalyst for change.

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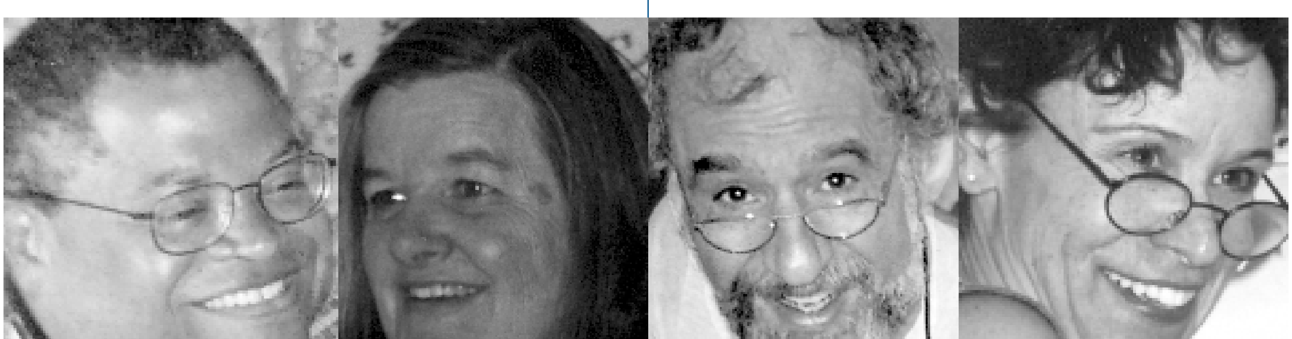

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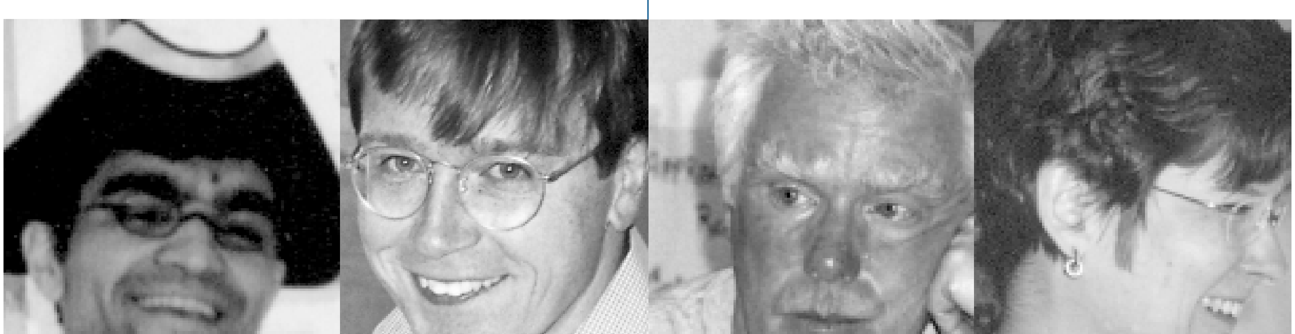

executive

National Conference on the Revolution in Earth and Space Science Education

Earth and space science education is undergoing a remarkable transformation. Long perceived as a "minor" science (in contrast with physics, chemistry and biology), Earth and space science is emerging in both public perception and active science research as a profoundly important field. Our lives and future depend on the depth of our understanding of our home planet. The concept of Earth as a rich and complex system of interconnected components and processes has become a dominant paradigm in science. Furthermore, the Space Age has provided a revolutionary new perspective on Earth, enabling us to see, explore and investigate our world in ways never before possible.

The National Science Education Standards underscore this transformation through a strong emphasis on "Earth and Space Science" as a core domain of science education at all grade levels. The Standards recommend that students experience Earth and space science as a process of inquiry, exploration and discovery. This is an ideal domain for inquiry, as the "lab" is all around us, inviting exploration.

Students should also tap into the power of telecommunications and visualization technologies to see the world from the unique perspective of space and use a wide range of data – just as scientists do. NASA, USGS, NOAA and other agencies have opened their treasure trove of satellite imagery, animations, interactive maps and other visualizations for ready access by schools and the general public. The Internet helps students see how Earth's forces affect their daily lives and provides direct access to news of Earth and space science and links for further exploration. These experiences help students understand Earth as a dynamic system – rather than simply a collection of topics to read about.

The potential impact on our schools and students is not just in Earth and space science, but in the broader applicability of the skills developed by students to related domains of science, math, geography and other fields. These thinking skills include inquiry, visual literacy, understanding systems and models, and the ability to apply knowledge and problem solving to a range of substantive, real-

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world issues. In short, this revolution in Earth and space science education has benefits for all students and for our relationship with our home planet Earth.

Recognizing the importance of these changes, the National Science Foundation funded the National Conference on the Revolution in Earth and Space Science Education. The conference took place June 21-24, 2001, in Snowmass, Colorado, with the goal of developing a vision and "blueprint" for K-12 Earth and space science education reform for the next decade. The conference assembled a broad spectrum of stakeholders including K-12 teachers and administrators, Earth and space scientists, university faculty, representatives of educational and scientific organizations, key people from government agencies, and people from allied domains such as biology, chemistry and physics.

The conference featured presentations on educational projects with cutting-edge curriculum, technology and professional development. It also focused on the challenges of large-scale reform in Earth and space science education. It looked at data on the remarkably low numbers of students currently participating in Earth and space science (only 7% of the nation's high school students take Earth and space science – as opposed to 88% that take biology). Working groups looked at ways to change the content and methods of Earth and space science education, and ways to greatly expand the number of students learning Earth and space science at elementary, middle- and high-school levels.

Summary of Recommendations:

Establish state-based alliances to promote Earth and space science education reform. Alliance partners should include educators, scientists, policy makers, businesses, museums, technology centers and others concerned about improving the caliber and scope of Earth and space science education. State alliances should develop and implement concrete plans to achieve the reforms outlined in this report. These alliances should be coordinated nationally.

Develop and conduct an "Annual Snapshot" to gauge progress toward meeting the goals outlined in this report. To measure improvements in Earth and space science education, we need to collect annual data on the current status of Earth and space science education nationally and in each state, including student performance, teacher professional development and curriculum reform, and monitor these changes over time.

Student learning experiences should have a stronger emphasis on inquiry-based learning, use of visualization technologies and understanding Earth as a system. These learning goals and teaching methods build on the National Science Education Standards and the Benchmarks for Science Literacy. They also reflect the nature and current practice of Earth and space science as well as the wealth of Earth visualizations and resources available through the Internet.

At the high-school level, Earth and space science should be approved as a lab science, with depth and rigor akin to biology, chemistry and physics. Earth and space science has changed dramatically since the time when it was often regarded as a lesser science in the panoply of high-school courses. Now Earth and space science is widely considered an essential element of a science-literate society. As a lab science, Earth and space science offers a rich array of challenging field work, lab experiments and advanced computer-based visualizations.

Develop a national database of high-quality, grade-level appropriate Earth and space science assessments. A national body of scientists and educators in Earth and space science education should create a databank of assessment items organized so teachers and others can construct high-quality measures of student achievement. This database should include not only good multiple-choice and constructed response items but exemplary, performance-based assessments and scoring rubrics for elementary, middle and high school. These assessments should measure student learning of the core concepts and skills identified for Earth and space science in the National Science Education Standards and Benchmarks for Science Literacy.

Create national and state professional development academies in Earth and space science. These academies should offer both summer institutes and school-year offerings, including online learning. They should model best practices in teaching, learning and assessment. Teachers should have an array of high-quality professional development opportunities, helping them

summary

experience Earth and space science as an engaging domain for inquiry, exploration and discovery.

In high needs schools, enhance access to high-quality Earth and space science education for students and professional development for teachers. All students should have the opportunity to do inquiry-based investigations of Earth and space whether they live in urban, rural or suburban areas. New curricula should include cultural and place-based perspectives, such as exploring Earth and space science in urban environments. Teacher training opportunities should include working with diverse populations.

Create new opportunities for students and parents to learn about Earth and space science in informal settings. Education should continue outside the classroom with strong support and involvement from parents and in collaboration with museums, science centers, planetariums and other centers of informal science learning.

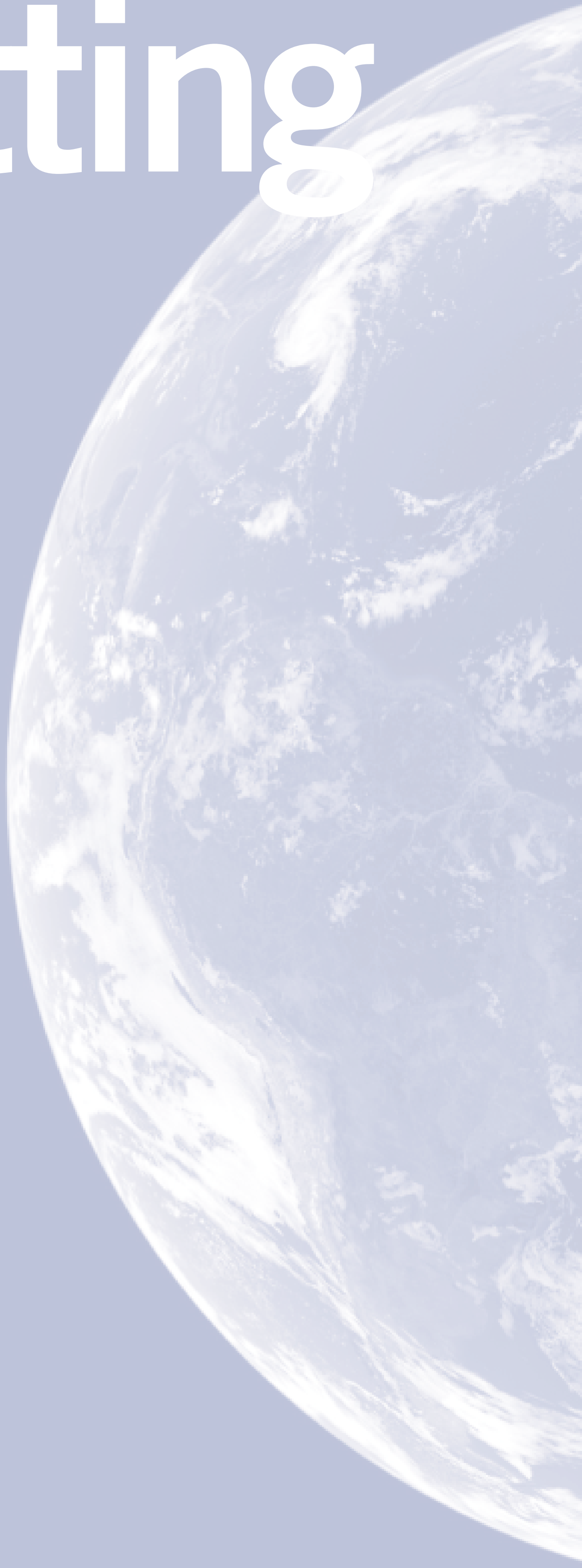
Develop a strong research program in Earth and space science education. Research on teaching and learning in Earth and space science education provides the basis for more effective curricula and teaching strategies, the appropriate use of new technologies in classroom and field settings, the professional development of teachers, and high-quality assessments.

The full report will be widely distributed, with the expectation that its recommendations will help shape the agenda, strategies and actions for Earth and space science education reform over the coming decade.

These revolutionary changes represent a timely and essential transfer of new Earth and space science knowledge, paradigms and tools from the science and education research community to the nation's teachers and students. This revolution in Earth and space science education will promote new, more effective approaches to teaching and learning. At a deeper level, this the revolution is essential to our future. A citizenry literate in the Earth and planetary sciences is essential for making informed political and economic decisions on local, regional and global levels.

For more information and a copy of the full report, visit the Web site:
www.EarthScienceEdRevolution.org.

setting



the stage

The Revolution

What is the Revolution in Earth and Space Science Education?

Earth and space science education is undergoing a revolution that is reshaping the nature and content of what is taught—with an increased emphasis on Earth as a system and expanded use of Internet resources. Students at all grade levels have greater opportunities to learn through inquiry, exploration and discovery, aided by expanded use of the Internet and visualization technology. Earth and space science, long perceived as a minor field compared to biology or the physical sciences, is emerging as a premier exemplar for innovation, quality education and successful science education reform.

This revolution has been years in the making and has required the leadership, vision, cooperation and hard work of a wide range of organizations and individuals. NASA, for example, has made major efforts to make readily available its resources of images obtained through remote sensing and other advanced visualizations. The National Science Foundation (NSF) has funded projects that led to innovative new curricula, technologies and professional development programs. The Coalition for Earth Science Education (CESE), an informal consortium formed in 1993, has promoted reform by encouraging collaboration among science and education organizations. And mainstream publishers, working with educators and curriculum developers, are beginning to reshape their textbooks so that technologies, including the Internet, become an intrinsic part of classroom lessons and homework activities.

Earth and space science has become a vital and exciting field rich with resources for teaching and learning. The diversity of organizations attending the National Conference on the Revolution in Earth and Space Science Education attests to the broad recognition of the sea change taking place in Earth and space science education. The potential impact on our schools and students is not just in Earth and space science courses, but in the broader applicability of the skills developed by students to related domains of science, math, geography and other fields. Furthermore, there is a growing number of jobs related to Earth science in fields as diverse as energy, resource management, emergency preparedness, space science and visualization technology. In short, this revolution in Earth and space science education is not just for "rock hounds." It is a revolution for all students, and for our relationship with our home planet Earth.

To make this revolution real, we need to focus on two broad goals: 1) changing the **Nature** of Earth and space science education and 2) expanding the **Extent** of student participation in Earth and space science education.

Revolutionizing the Nature of Earth and Space Science Education

Here is a way to envision the changing nature of Earth and space science education. Think of a traditional middle-school Earth science class in plate tectonics. Students might read from a textbook, learning how plate tectonics cause earthquakes and volcanoes, and then answer a few questions in the chapter review section of the book. Essentially, the experience is read the book and answer the questions.

Now let's visit a middle-school classroom participating in NASA's EarthKAM project (www.EarthKAM.ucsd.edu). EarthKAM provides students with direct access to a digital camera flown on the International Space Station (ISS). Students use the Internet to select interesting targets along the Station's orbital track, send the requests to the camera and then download the images to use in their Earth science classes. In this example, students apply what they learned in their textbooks by selecting as targets volcanoes along plate boundaries. These images become the focal point for a series of inquiry-based investigations, as students interpret the images, compare different volcanoes, map their locations and correlate the images with news reports of currently active volcanoes. In other words, the student experience is changed from simply reading Earth science to actually doing Earth science.

This example illustrates three key elements of the changing content and methods of Earth and space science:

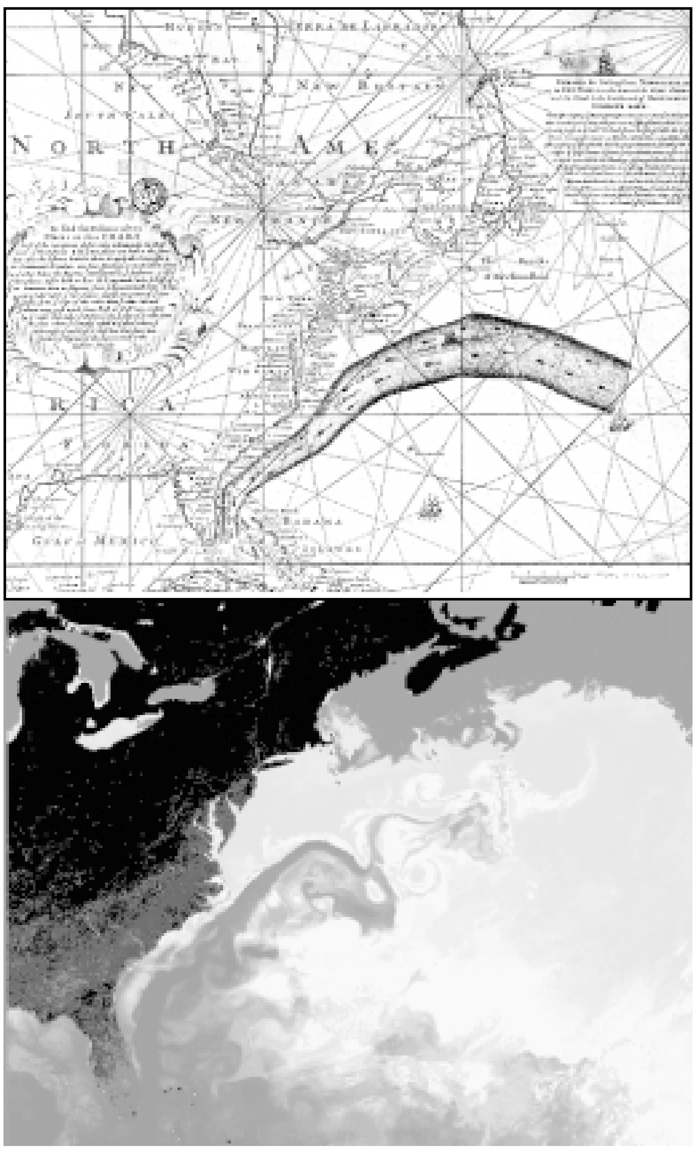
Science as inquiry – The National Science Education Standards are quite explicit in their emphasis on inquiry-based learning: "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science." Earth and space science is an especially rich domain for inquiry because the "science lab" exists all around us. Students experience Earth and space science going to and from school, on field trips, in the daily news and through Internet resources.

Earth as a System – Understanding Earth as an integrated system of components and processes has become the dominant paradigm in Earth and space science research – and should become the central unifying principal in Earth and space science education as well. Students should not experience Earth and space science as a series of topics, but rather as a whole system – the interconnected geosphere, hydrosphere, atmosphere and biosphere. The National Science Education Standards consider "systems and models" as one of the key "unifying concepts and processes."

Internet and visualization technology – The Internet is now pervasive in schools. While Internet speeds and ease-of-access may not be ideal in all classrooms, the predominant reality is that the Internet is available and schools are looking for the best ways to use its power. Earth and space science may be the most powerful domain for the Internet, with the incredible wealth of visualizations to support student learning. In the EarthKAM example, the Internet provides students not just with access to the images, but also with the ability to select new targets for the camera on the International Space Station.

Other examples of innovative projects that augur the revolution in the nature of Earth and space science education are described elsewhere in this conference report, including the American Geological Institute's EarthComm (relating Earth and space science concepts to student's local regions), AMS's DataStream (providing weather data for student investigations), and the Digital Library for Earth System Education (DLESE), a national clearinghouse for Earth and space science data, visualizations and learning activities at all grade levels). As further evidence of the large-scale impact of this revolution, the major publishers of Earth and space science textbooks are providing Internet resources keyed to topics in the textbooks.

Gulf Stream as mapped by Ben Franklin (above) and as depicted by satellite (below)



Revolutionizing the Extent of Student Participation in Earth and Space Science Education

The nation needs to increase the number of students, the amount of time and the types of opportunities for learning Earth and space science at elementary, middle- and high-school levels. This also includes efforts to broaden the diversity of students learning Earth and space science. Policy reform and expanded opportunities for professional development are essential for achieving these goals.

The scope of the challenge can be seen in a few key statistics. Of the roughly 13 million high school students in our nation, only 7% (860,000) will take a high-school Earth and space science course. Contrast this with roughly 88% of students who take biology. Only two states (North Carolina and Kentucky) require Earth and space science for graduation, and 17 states do not even consider Earth and space science as a standard lab science course (National Report on the Status of Earth Science Education, AGI, 2001). California and Texas, for example, accept biology, chemistry and physics as lab sciences, but not Earth and space science (except under special circumstances). Ironically, both of these states are significantly impacted by Earth and space science related issues, such as allocation of water and energy resources, and risks from natural disasters like hurricanes and earthquakes.

Hence a major challenge, and opportunity, is to greatly expand the number of students participating in Earth and space science at the high-school level. As detailed in this report, we believe real progress can be made in this regard by enhancing the nature of Earth and space science, and by ensuring that all states accept Earth and space science as a lab course.

For middle and elementary school students, statistics are harder to come by, but it is a safe assumption that their experiences in Earth and space science education are generally less than optimal. This is ironic since Earth and space science is such an accessible domain of science learning, as it relates directly to students' immediate environment and daily experiences, and is full of opportunities for hands-on learning.

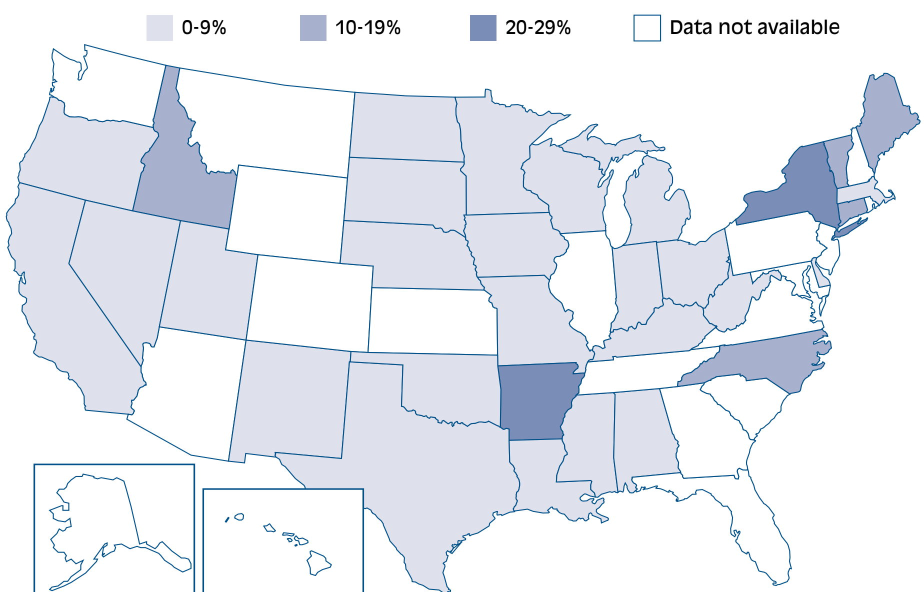
The growing presence of computers and Internet access in schools provides a strong opportunity and impetus for reform. There are currently over 8 million computers in schools and 98% of schools have at least one Internet-connected computer. Computers are now the norm rather than the exception. Earth and space science provides a very compelling context for using computers in powerful ways to support student inquiry, exploration and discovery.

State-by-State Policy Reform – In many ways, reform efforts need to focus on individual states since the educational requirements, curriculum frameworks, assessments and teacher professional development are essentially determined at the state level (for details on each state's policies and practice, refer to the AGI Report on the Status of K-12 Earth and space science Education at www.agiweb.org/education). In spite of the relatively low levels of current participation in Earth and space science, there is considerable cause for optimism. In an informal 2000 study by TERC of all 50 state departments of education, 64% reported a growing interest in Earth and space science education.

As one example, in 1998, the Massachusetts Department of Education released a draft framework for science education that eliminated Earth and space science at the high-school level. Over the ensuing several months, a wide range of educators, scientists and other interested individuals and organizations mobilized for the reinstatement of Earth and space science. The revised framework has now been released and approved – including reinstatement of Earth and space science at the high school level. Clearly the perception of Earth and space science education is changing, with a growing recognition of its impact and importance.

One key recommendation of this conference is to establish state-based alliances for reform of Earth and space science in each state, and to coordinate these efforts through a national network. This recommendation builds on the experiences of the National Geography Alliance, which used a comparable model to promote reforms in geography education.

PERCENT OF HIGH SCHOOL STUDENTS TAKING EARTH SCIENCE IN 1997-1998
Contrast with national average of 88% students taking Biology



AGI National Status Report on K-12 Earth Science Education

Expanding Diversity – Diversity is an especially important challenge in Earth and space science education reform. Earth and space science is often perceived as more appropriate for schools located in rural or other areas that might be considered "closer to nature." This perception is far from the truth.

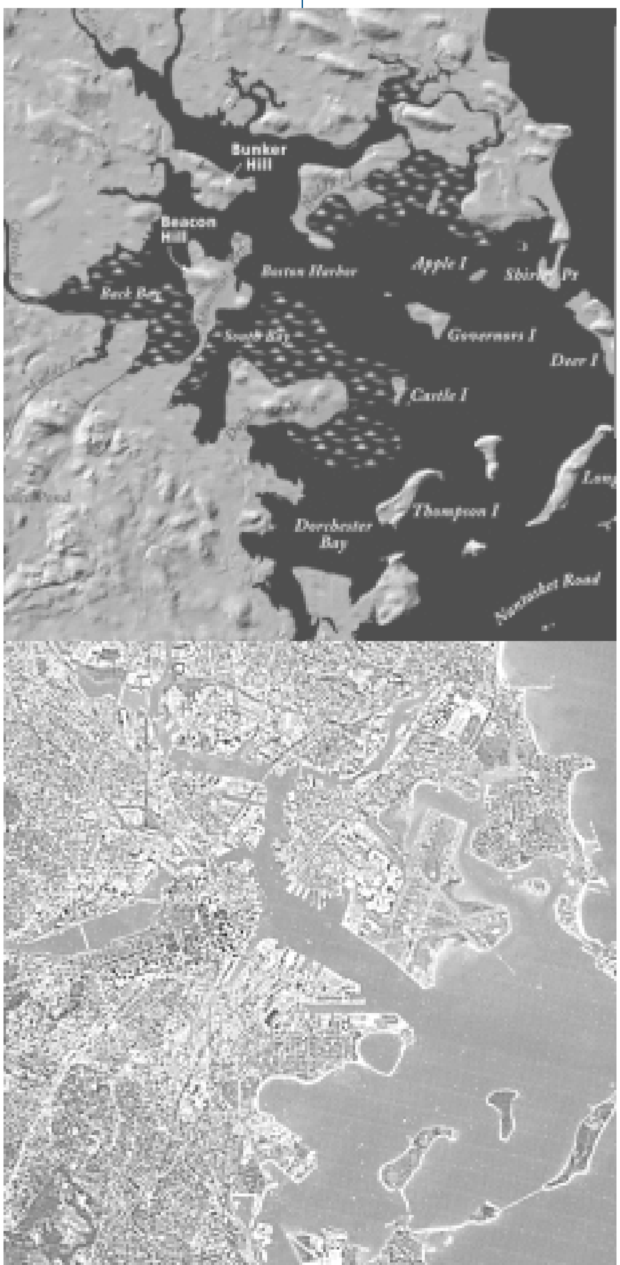
In reality, urban areas are very closely connected to the environment. Cities are often founded near rivers and grow in patterns defined by the physical environment. Construction of buildings and highways require deep knowledge of what lies underground. Natural disasters such as severe weather or flooding require careful planning and recovery. All of these are rich domains of study for Earth and space science classes, ripe with real-world topics for inquiry and investigation. Furthermore, cities are "data rich" with a wealth of aerial and satellite imagery, environmental measurements, sub-surface data from construction sites and so on.

Earth and space science is thus a field where urban schools should be at the cutting edge of the revolution rather than the trailing edge. Each city might develop its own inquiry-based units on topics of local relevance. For example, Boston might focus on its changing landscape, as it filled in wetlands, bays and other coastal areas to provide more land for housing and business. Los Angeles might focus on how access to water became the defining factor in its growth. St. Louis might focus on flooding and evacuation patterns. In each case, the urban aspect provides a human element, showing the relevance of Earth and space science in our daily lives. These examples also strongly illustrate the interconnections among the components of Earth as a system, as the systems play out on local and regional levels and varying time scales.

We perceive the revolution in Earth and space science education, including changes in both its nature and extent, to be driven by strong and compelling forces. Quoting from the statement approved by conference participants:

"Fueled by new technologies over the last forty years, advances in Earth and space science are revolutionizing our understanding of Earth's systems and processes. This growing understanding is increasingly needed to inform political and economic decisions of local, national and global impact.

For this reason, a science-literate citizenry is vital to the nation's well-being and security and will ensure our nation's continued leadership in science and technology in the 21st century. To empower the public to make sound and reasoned choices, Earth and space science must be taught throughout the United States in K-12 classrooms and be accessible to all students."



urban investigations

Urban environments offer especially rich opportunities for students to learn, explore and apply Earth science.

For example, the shape of Boston has changed dramatically over the past few hundred years, as settlers filled in large sections of Massachusetts Bay to provide more space for homes and businesses.

The image above illustrates the landforms roughly 1,000 years ago, vs the same region as seen in a recent satellite image.

A National Strategic Imperative

Earth and space science is of national strategic importance. To understand why, one needs to consider what Earth and space science is. Earth and space science is an integration and synthesis of physics, biology, chemistry, geology, oceanography, meteorology and all other sciences that study life, Earth and the heavens. Fueled by 21st century technologies like data visualizations, analysis tools, remotely-sensed imaging and satellite photography, it consolidates these fields to offer new systemic understandings of Earth's components. Over the last fifty years, Earth and space science has revolutionized how we view and know Earth and its systems.

This accumulating body of knowledge, however, is far from academic. Our quality of life, it is fair to say, depends on the quality of our Earth scientists. This is because understanding the land, air, water and life of our planet gives us the knowledge to best manage the world around us. Earth and space science enables us to learn from the past and prepare for the future. The procurement and use of all major energy sources—fossil fuels, solar, hydro and wind—are the direct result of Earth and space science. The same is true of our water supplies and renewable and non-renewable resources. How we use the land and build our cities, bridges and roadways are all determined by Earth and space science. Earth and space science allows us to forecast the weather, volcanoes and earthquakes, helping us to protect vulnerable populations from the forces of nature, and it informs us about sustaining growing populations, developing adequate food supplies and managing waste. Earth and space science addresses pressing environmental issues such as ozone depletion, global warming and threats to marine life.

From community development to resource planning, from emergency preparedness to energy management, we, as citizens, are increasingly called upon to make vital policy decisions that affect, if not define, our lives, the economy and the national well-being. We must know how to critically evaluate data, investigate the world around us, and assess environmental and economic impacts of our actions. To empower the electorate to arrive at informed and reasoned choices, our educational infrastructure must effectively teach Earth and space science to generation upon generation of students. Whether as citizens or as professionals, we require literacy in Earth and space science to ensure our prosperity.

Earth and space science education offers extraordinary opportunities for teaching scientific inquiry and critical-thinking skills, which have benefits even outside the field. Earth and space science is the most unifying domain in

Imperative

science and to learn it, students must amalgamate many basic disciplines to see life and nature as comprised of dynamic, interdependent systems. They also must become familiar with models, data analysis, visualizations, technologies and interdisciplinary thinking, all of which are increasingly important in the workplace.

Earth and space science is vital for expanding human knowledge and essential for the nation's future. It is these urgencies that drive the Revolution in Earth and space science education.

An Educational Imperative

Earth and space science education is about the planet we live on, the third planet from the sun and the only known place in our universe where life occurs. It is about four and a half billion years of history involving fantastic stories of climate change, evolution and extinction. It is about a planet alive with fiery volcanoes, sudden earthquakes, slow-moving glaciers and fast moving storms. It is about a planet of rich resources, beautiful natural wonders, and amazing plant and animal species.

Earth and space science education at its most basic level is about observing the world around us and asking questions. As young children we taste, touch, smell, see and listen. We ask questions about rocks and sand, about clouds and rain, about the moon and stars. As we grow older and our questions, observations and sampling techniques become more sophisticated, we learn that Earth and space science education is the study of a complex system of interacting chemical, physical and biological processes, constantly changing, ever surprising.

All of us who live on this planet have the right and the obligation to explore and understand Earth's unique history, its dynamic processes, its abundant resources and its intriguing mysteries. As citizens of Earth, with the power to modify our planet's climate and ecosystems, we also have a personal and collective responsibility to understand Earth so that we can make wise decisions about its and our future. The "Revolution in Earth and Space Science Education" is about ensuring that all citizens have the opportunity to learn the science of their planet from pre-school through college and beyond. We invite you to join us on this 21st century voyage of exploration, discovery and change.

Earth Literacy

National Conference

National Conference on the Revolution in Earth and Space Science Education

Colorado State University's Center for Science, Mathematics, and Technology Education (CSMATE) in cooperation with TERC and with support from the National Science Foundation (NSF) convened a workshop from June 21-24, 2001 in Snowmass, Colorado to define a common vision for Earth and space science education in grades K-12 during the next decade. An advisory committee met in April 2000 at NSF and several times via email during the subsequent year to develop the goals and agenda for the workshop and to identify workshop participants. We recognized that to have a positive and sustainable impact on K-12 Earth and space science education, this effort would need to take a systemic, collaborative and long-term approach to reform. Consequently, while about half of the participants selected were K-16 educators, scientists, business leaders, and administrators in the Earth and space sciences, the other half were from physics, chemistry, biology, geography, mathematics and policy areas. Represented organizations included National Science Teachers Association, American Association for the Advancement of Science, Biological Sciences Curriculum Study, American Chemical Society, American Institute of Physics, National Association of Geoscience Teachers, and National Earth Science Teachers Association. Government agencies included the National Science Foundation, NASA and United States Geological Survey.

In taking a systemic approach to reform, eight areas of broad interest were identified to focus workshop discussions and report recommendations. These areas were:

- → Policy and Systemic Reform
- → Curriculum and Instructional Materials
- → Technology
- → Assessment
- → Professional Development
- → Partnerships and Collaborations
- → Equity and Diversity
- → Informal Education and Outreach.

Working groups in each of these areas were formed based on the expertise of the participants and with the goal of seeking broad representation of grade levels, disciplines and demographics. Prior to the workshop, each working group was asked to address key questions concerning the current status of their topic area with respect to Earth and space science education. At the workshop, each working group met several times in small group sessions to develop reports and recommendations for the future. Plenary sessions set the stage for the work to be done, calibrate participants on the current state of Earth and space science education, develop a common vision for the future of Earth and space science education, allow for the sharing of information and ideas between groups, and to summarize the recommendations of each group. Following the workshop, the working group facilitators and a small number of other participants worked with the conveners to draft the initial sections for this report.

The **Blueprint for Change** report resulting from this workshop is the first collective response from the Earth and space science education community to the National Science Education Standards, the Benchmarks for Science Literacy, and new State Science Education Standards. We hope that teachers, administrators, policy-makers and parents use this report as a resource and guide to Earth and space science education reform efforts in classrooms, school districts and communities across the country. This report is also intended to be an invitation to other disciplines to support collaborative, large-scale education reform efforts in science, geography, language arts and technology.

Participants of the National Conference on the Revolution in Earth and Space Science Education.

Working Group 1

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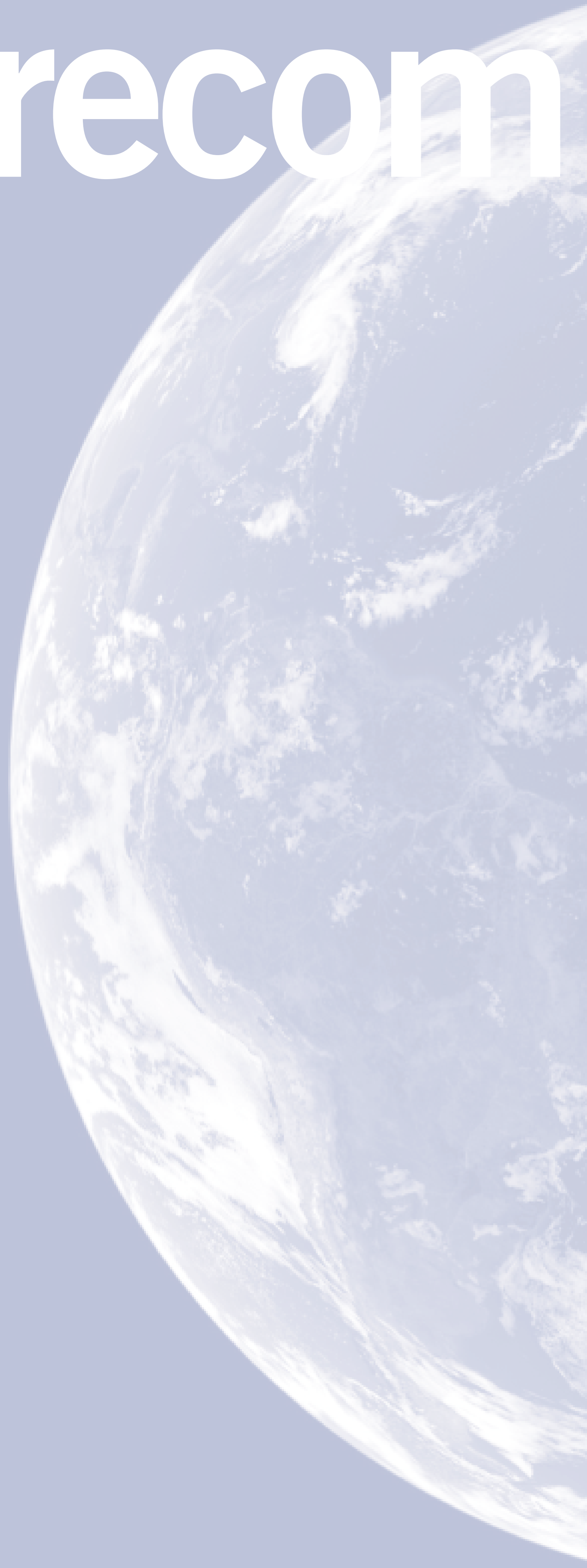

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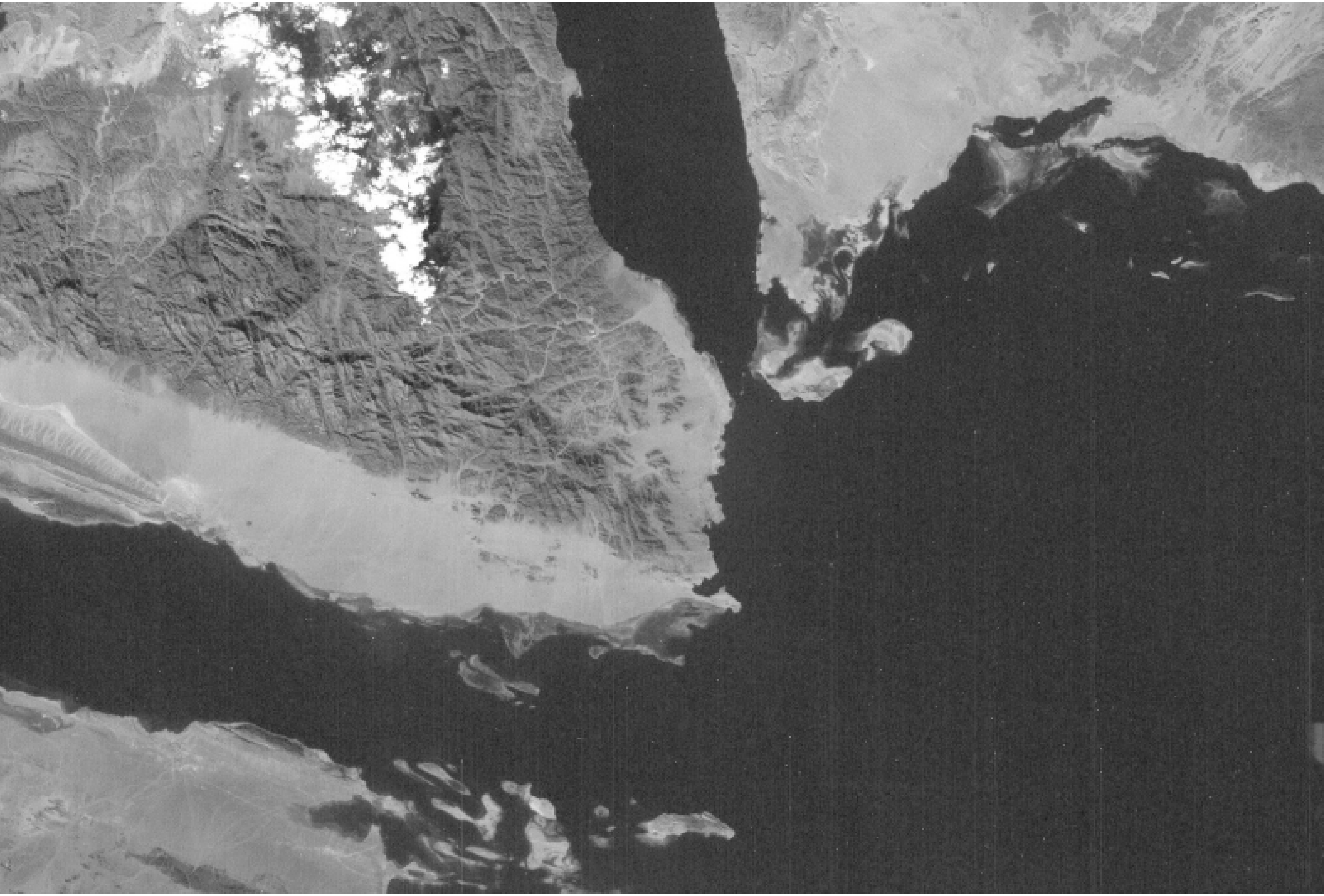


Systemic Reform

Policy and Systemic Reform

To ensure every student receives quality instruction in Earth and space science, we need to elevate the visibility and commitment to Earth and space science education on a policy and systemic level. Comprehensive policy and systemic reform is needed on district, state and federal levels. Only then can stakeholders coordinate resources and strategies and institutionalize Earth and space science education into the fabric of K-12 education.

Throughout this document, specific recommendations are provided relating to each aspect of reform. All of these recommendations have policy implications. Here are some recommended policy initiatives and approaches to systemic reform that will enable us to better define, fund and implement the new approaches presented throughout this proposal.

As we make these recommendations, we acknowledge that many fit into a larger context. Earth and space science education reform is in many ways part of the more comprehensive efforts to improve science, mathematics and geography education in general. For example, our recommendations for improved teacher professional development in Earth and space science education closely mirror recommendations of the National Commission on Mathematics and Science Teaching for the 21st Century (known as "the Glenn Commission"). Similarly, our recommendations for state-based partnerships closely mirror aspects of the new National Science Foundation (NSF) Math and Science Education Partnerships program. The focus on states as the locus of change parallels the work of the NSF, NASA State-Systemic Initiatives and the National Geography Alliance. Hence, our recommendations should be seen as part of the larger fabric of federal, state and local policy reform for science education.

Policy and Systemic Reform

Recommendations:

Coordinated efforts across all sectors of the education system within a region (federal, state, local and non-profit sectors) need to occur simultaneously and they need to be sustained for change to occur.

Federal Level.

1. Federal funds should support Earth and space science education initiatives in such areas as materials development, teacher training, new technologies, assessment and accountability.

Specific details are provided in the respective sections of this proposal. Funding for these initiatives are part of the larger support for science education reform, and should be implemented through peer review programs administered by federal, state and local organizations, such as the National Science Foundation, NASA, the Department of Education, and other relevant groups.

2. Federal funds should support partnerships for Earth and space science education reform.

Such partnerships should include scientists, educators, businesses, technology specialists and others involved in Earth and space science education. They should build on their respective areas of expertise and provide a synergy to shape and implement reforms. New Math and Science Partnership programs are ideal vehicles to support these reform efforts.

3. Federal agencies involved with Earth and space science research should support and require linkages with formal education and public outreach initiatives.

NASA, the United States Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA) and other federal agencies that conduct research in Earth and space science education should continue and expand their initiatives for formal and informal science education and for public outreach. For example, many of NASA's Earth and space science initiatives already require that the learning of science by all Americans be built into the programs. NOAA posts current weather data and satellite images on public Web sites for free public and education access. Such efforts should be continued and expanded, including developing related educational materials to help teachers and students take better advantage of these resources.

4. A key person knowledgeable about both education and science should be identified in each of several federal agencies to serve as the agency's primary point of contact and chief advisor for Earth and space science education.

NASA already has established a lead person for education for the Earth and space science Enterprise and the USGS is creating a similar position to manage its education efforts. Similarly, other agencies, such as NSF, Department of Education and the Office of Science and Technology Policy should identify a key contact, such as a director or advisor for Earth and space science education. These individuals should actively work with each other and with the Earth and space science education community to leverage available resources.

5. Federal funds should support a program to evaluate the effectiveness of Earth and space science education as an annual "snapshot" of progress.

Such an annual snapshot would integrate a set of formal and informal measures to assess the status and progress of reform. These would include: relevant Earth and space science data from the National Assessment of Educational Progress (NAEP) and other standardized tests; data on numbers and training of teachers and students in Earth and space science courses at different grade levels; progress in the use of authentic data, analysis tools, the Internet and visualization technologies in these courses; data on public attitudes toward Earth and space science; a measure of informal Earth and space science education reaching the general public; and examples of cutting-edge innovations. Such a report will help us monitor progress and identify methods and approaches that have high returns on investment.

State Level

6. All states should offer Earth and space science curricula and should review their Earth and space science education frameworks to ensure that they reflect the revisions in content and methods proposed in the National Science Education Standards and in this report.

Although the National Science Education Standards (NSES) define standards for curriculum and pedagogy, they are guidelines rather than mandates. States, in fact, are the primary locus of control for curriculum and pedagogy, embodied in what are usually called frameworks for science education. Each state should review its frameworks for Earth and space science education to ensure that the content and pedagogy are in line with the NSES. Close attention should be paid to Earth as a system as the central paradigm, science as inquiry as a dominant approach to teaching and learning, and integration of computer-based analysis tools, Internet and visualization technology into the curriculum. Such frameworks should also include explicit linkages between key concepts in Earth system science, advances in basic scientific knowledge and each state's local environment (such as its geologic history, land use patterns, air and water quality or natural hazards).

California Science Teachers Join the Revolution

CALIFORNIA SCIENCE TEACHERS JOIN THE REVOLUTION

To improve science education in the state, the board of the California Science Teachers Association (CSTA) formally ratified in December 2001 the manifesto, "Declaration of Importance," drafted by the National Conference on the Revolution in Earth and Space Science Education. (See page 97.)

CSTA's clarion call is part of the California Earth Science Initiative, which seeks to elevate Earth science to a status equal to the physical and biological sciences. The Initiative is exploring such strategies as:

- → developing a California coalition of stakeholders including professional Earth science organizations, business, government agencies, and universities to develop ways to promote Earth science education and implement existing state policy (Earth science standards).
- → developing a professional development strand for Earth science education at CSTA conferences.
- → devoting future editions of CSTA's publication, the ***California Journal of Science Education*** to Earth science themes.
- → seeking high-quality Earth science materials for CSTA to publish.

Moreover, to further support Earth science education reform on a national level, CSTA will join the Coalition for Earth Science Education (CESE), an informal, national coalition of education and scientific organizations involved in Earth and space science education reform.

"CSTA's goals are to improve science education in California and improve scientific literacy of the citizenry in general," said Dick Filson, president of CSTA. "The work of the board of directors ensures that CSTA will continue to build on its successes and expand its influence on science education."

cascience.org/

7. States should review their methods and tools of assessment to ensure that they mirror the revisions in the curriculum frameworks.

Just as states should review their curriculum frameworks, so too should they review their assessment methods and tools. Curriculum reform and assessment reform must go hand-in-hand. Specifically, there should be increased attention to assessing high-priority skills such as inquiry, investigation, critical thinking and analysis, and unifying concepts such as Earth as a system and effective use of visualizations to support learning and research. These are typically under-emphasized in current assessment tools.

8. States should create incentive programs to produce, recruit and retain Earth and space science teachers, as well as implement sustained professional development for them.

Such incentive programs are essential, given the shortfall of trained teachers in Earth and space science. Examples of incentive programs include cash bonuses, grants of computers, reduced Internet access rates and mentorship support for new teachers. Each state should support teacher certification in Earth and space science, and should encourage and assist scientists to become teachers. Professional development should be ongoing, as detailed in the Professional Development section of this report.

9. Establish state-based alliances for Earth and space science education in every state.

In support of the state-based initiatives, each state should establish an alliance for Earth and space science education reform, including policy makers, educators, scientists, businesses and other key stakeholders. The alliances will coordinate efforts and help to ensure that the diverse components (e.g. curriculum reform, assessment, professional development) are in alignment. These alliances promote and ensure state ownership and sustainability of reform efforts. Further details are provided in the Partnerships section of this report.

District Level

10. Implement Earth and space science education reforms through local policy and practice in alignment with state and national standards.

Ultimately, successful implementations of the reforms advocated here take place at the local level, in individual classrooms with individual teachers based on local policies and practice. Hence, the reforms need to be understood, accepted and approved at the district level and by parents. Districts should ensure that their Earth and space science curricula and materials support the reforms in content and pedagogy detailed throughout this report. They should support expanded use of new technologies, providing students and teachers with ready access to the Internet and to related tools for analysis and visualization. Districts should be clear about their support of inquiry-based learning. They should ensure that assessments go beyond simple facts and vocabulary knowledge to also include deeper concepts of Earth as a system, interactive exploration using tools of technology, and inquiry-based learning.

Additionally, to ensure effective instruction, districts should implement the 24:1 class-size cap, as advocated in the NSTA position paper on class size. They should identify local resources to support reform of Earth and space science education, and should make connections between concepts taught in Earth and space science classes and the local environment. And districts should ensure the integrity and continuity of the Earth and space science education program from elementary through middle- and high-school levels.

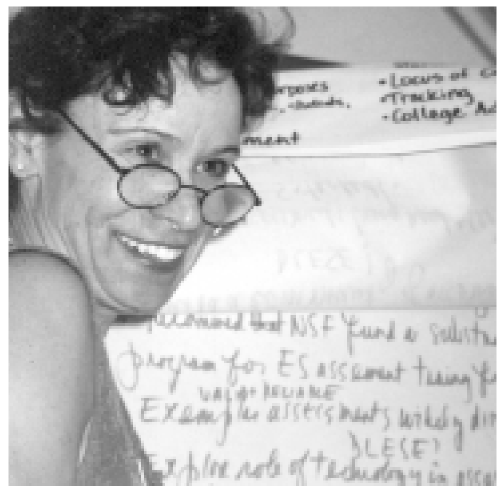
Careers in Earth Science

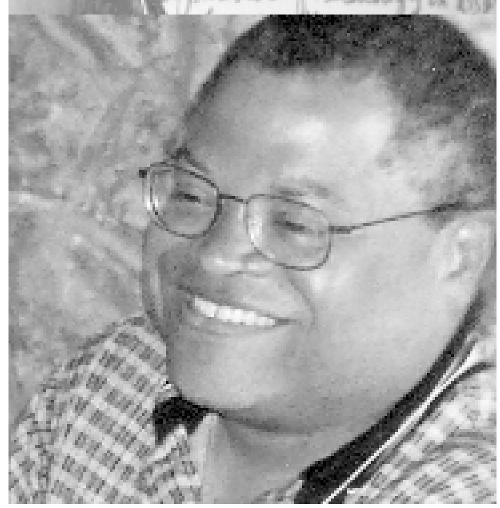
CAREERS IN EARTH SCIENCE: IMPROVING THE QUALITY OF LIFE AND EXPANDING THE BOUNDARIES OF KNOWLEDGE

Earth science offers rich professional opportunities for students. The private sector, from construction and engineering to energy and agriculture, increasingly demands qualified Earth and space scientists. Likewise, local state and federal agencies, like NASA, the Department of Energy, the Department of Agriculture and the armed forces, depend on Earth science to meet their missions and serve the public.

Below is a very partial list assembled by the American Geological Institute of some of the professional opportunities available in the burgeoning field of Earth science.

Atmosphere scientists
City and regional planners
Economic scientists
Engineering geologists
Environmental geologists
Geochemists
Geochronologists
Geologists
Geomorphologists
Geophysicists
Glacial geologists
Hydrogeologists
Hydrologists
Marine geologists
Meteorologists
Mineralologists
Oceanographers
Paleoecologists
Paleontologists
Petroleum geologists
Petrologists
Planetary geologists
Sedimentologists
Seismologists
Soil scientists
Stratigraphers
Structural geologists
Volcanologists





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Curriculum and Instructional Materials

Curriculum

Curriculum lies at the core of classroom education. High-quality Earth and space science curriculum offers wonderful opportunities to challenge and engage students with inquiry-driven learning and exploration. It guides them through the process of scientific discovery, enabling them to understand key concepts and acquire vital skills. It empowers them to use authentic tools and techniques of Earth and space science, as well as its imagery, visualizations and data. And it makes science real by connecting students to their environments, communities and daily lives.

Curriculum is generated around developmentally-appropriate learning goals. It specifies instructional materials and methods and a program of teacher and student activities designed to achieve these goals. To measure whether these goals are met, it includes multiple forms of embedded assessments. The best curriculum is organized sequentially so that prior learning provides the foundation for later learning, including both content and skill development. The implementation of curriculum requires quality instructional materials, including textbooks, classroom activities, computer and Internet resources, and hands-on materials for the laboratory and field.

Earth and space science education features exemplary instructional materials developed by commercial publishers, colleges and universities, and curriculum developers. The National Science Foundation (NSF), NASA and others have funded many innovative curriculum projects. However, their implementation in classrooms is often fragmented and imperfect. There is also an increasing amount of digital Earth and space science data available from the scientific community, distributed by agencies such as NASA, the United States Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), and others. In most cases, however, neither the instructional materials nor the data are organized and presented in such a way that teachers can readily incorporate them into their teaching. There is a pressing need to organize, inventory, evaluate, and then disseminate these exemplary materials to classroom teachers.

In the 21st century, curricula must reflect new learning strategies and technologies. Curricula should move away from the passive reading of textbooks to dynamic pedagogical approaches that support authentic student investigations and the development of skills of inquiry, exploration and discovery. Curricula need to support student use of current and emerging technologies, such as Web-mediated remote sensing and data visualizations, as essential learning tools in the classroom and at home. The result will be generations of scientifically- and technologically-literate young adults contributing to both the workplace and society.

Curriculum and Instructional Materials

Recommendations

1. To enhance classroom learning and teaching, K-12 Earth and space science curricula should:

→ ***engage students*** – Curricula should offer dynamic learning opportunities that are relevant to students' lives and communities.

→ ***be inquiry-based*** – Curricula should enable students to conduct their own investigations, making scientific observations, offering hypotheses and experiencing the thrill of discovery just as Earth scientists do.

→ ***present the natural processes of Earth as interconnected systems*** – Students should learn the systems and processes of the Earth's atmosphere, lithosphere, hydrosphere and biosphere and how they interact.

→ ***utilize space-age perspectives, authentic data and current technologies*** – Curricula should empower students to utilize the wealth of Earth-orbit images, data and tools that scientists gather, evaluate and disseminate on the Web.

→ ***illustrate how Earth and space science reflects the contributions of and is relevant to diverse populations*** – Curricula should present the rich diversity of scientists and thinkers who, over time, contributed to our understanding of Earth and space, enabling students to trace the discoveries and technologies that built our knowledge.

→ ***provide opportunities for field research by students*** – Curricula should allow students to conduct hands-on investigations on their school grounds, in their back yards and throughout their communities.

→ ***be developmentally appropriate*** – Curricula should be tailored to the grade and skill levels of targeted student populations.

→ *provide a forum for the development of skills in math, geography, reading and writing* – Earth and space science offers broad, multidisciplinary learning opportunities in math, reading and writing that should be embedded in classroom curricula.

→ *serve as tools for teacher professional development* – Curricula should enable and encourage teachers to advance their knowledge and teaching skills in Earth and space science.

2. Development of K-12 Earth and space science instructional materials should conform to accepted professional practices and standards. These practices and standards include:

→ teacher participation in the development process

→ pilot and field-testing of materials with students in representative demographic settings

→ evaluation of student learning

→ scientific review of content accuracy

→ alignment with student learning goals derived form the National Science Education Standards and Benchmarks for Science Literacy as well as state science, math, geography and technology education standards.

3. Encourage school systems to teach Earth and space science throughout K-8 and as a full-year course in high school.

Earth and space science will grow in importance in the 21st century as the public increasingly relies on its findings to inform decisions of social, political, economic and environmental impact. For these reasons, we follow the lead established by the National Science Education Standards and Benchmarks for Science Literacy in calling for Earth and space science to be a strand of science curriculum at every grade level from K-8 and a full-year course at the high-school level. Earth and space science integrates key areas of science, such as biology,

Exploring Earth: Infusing Innovation

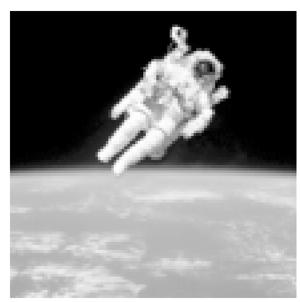
EXPLORING EARTH: INFUSING INNOVATION INTO MAINSTREAM CLASSROOMS

Exploring Earth, funded by the National Science Foundation (NSF), infuses innovative Earth science materials and resources into mainstream classrooms. The pioneering project is a partnership between the Center for Earth and Space Science Education (CESSE) at TERC, an innovative developer of science, technology and math education materials based in Cambridge, MA, and McDougal Littell, a publisher of widely-used middle and high school textbooks. Together they are revising the popular McDougal Littell Earth Science textbook to produce a curriculum program that integrates the textbook with Web-based resources.

Exploring Earth features the power of visualizations and interactive investigations to help students learn core concepts in Earth and space science and carry out inquiry-based investigations. These visualizations and investigations are integrated with the textbook. As students read the textbook, they see direct references to related visualizations and investigations available on the Web. The Internet is fully integrated into classroom learning and no longer a separate and, at times, overwhelming resource for teachers. Every Web page has been designed with novice users in mind.

Images and interactive animations of Earth provide a rich and visual perspective to help students relate what they read in the textbook to what happens in the real world around them. Students can see volcanoes erupting, weather storms forming and dissipating, ocean currents flowing in global patterns, and the latest images from spacecraft exploring other worlds.

Exploring Earth attempts to solve a problem often confronted by developers of innovative, or even revolutionary, new approaches to science education—how to integrate them into standard classroom practice. Through this partnership between TERC and McDougal Littell, the new resources are directly infused into the more traditional textbook program, combining comprehensive content with dynamic learning opportunities. This synergy of expertise and resources illustrates the power of partnerships to promote science education reform.

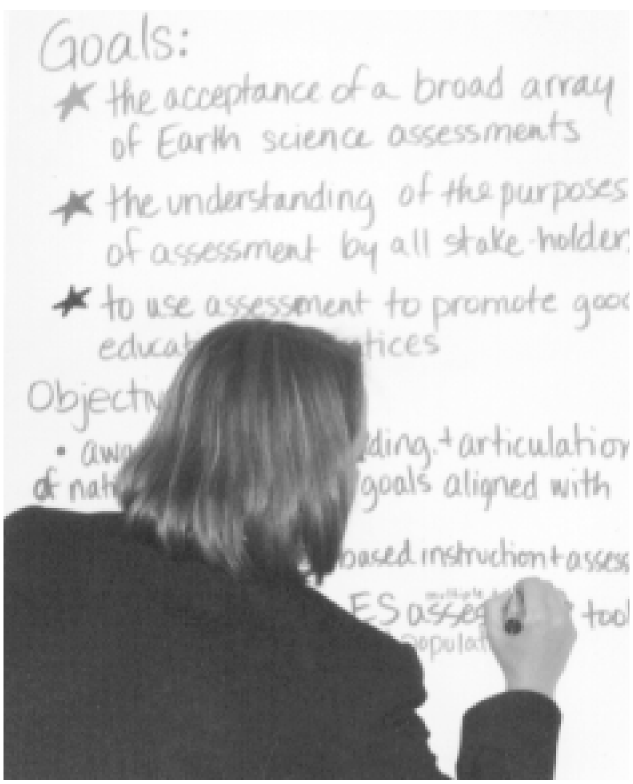


www.classzone.com

chemistry, physics, geology and astronomy, and offers a cohesive educational framework for these disciplines.

4. Develop a set of core learning goals for Earth and space science education that expands and elaborates the goals set forth in National Science Education Standards.

There is a need for greater coherence in curriculum development at the state and local levels. The National Science Education Standards and the Benchmarks for Science Literacy set forth in broad strokes the learning objectives for K-12 science education. However, as state and local education authorities work to develop specific versions of these standards in the form of state frameworks and district curricula, they would benefit from specific, detailed descriptions of the learning goals embodied in the standards. These specific core learning goals and assessments to accompany them should be developed by a national-level working group comprised of leading Earth and space science educators and scientists.



5. At the high-school level, Earth and space science should be approved as a lab science with a level of depth and rigor akin to biology, chemistry and physics.

As a field of science and as a course of study, Earth and space science has changed dramatically since the time when it was often regarded as a lesser science in the panoply of high-school courses. Now Earth and space science is widely considered an essential element of a science-literate society, helping us to understand and deal with a growing array of issues of local, national and global importance. Furthermore, the scope and depth of knowledge encompassed in Earth and space science has deepened, including the integration of fundamental concepts in geology, oceanography, meteorology, astronomy and biology. As a lab science, Earth and space science has moved over the past few decades from what might have been a few experiences with rock identification, to a rich array of challenging field work, lab experiments and increasing use of advanced computer-based visualizations. The National Science Education Standards underscore this importance by confirming that Earth and space science should be a standard part of elementary, middle- and high-school science programs.

Therefore, every state should ensure that Earth and space science is approved as a lab science, satisfying graduation requirements in the same way that physics, chemistry and biology do. Similarly, colleges and universities should accept Earth and space science as meeting high-school science requirements.

6. Create and sustain an instructional materials review process and a database of reviews maintained at the Digital Library for Earth System Education (DLESE).

Districts, schools and teachers are confronted with a wide range of Earth and space science instructional materials that they may select in developing curricula, but nowhere is there an accessible database of objective, authoritative reviews of these materials. DLESE, as a portal to high-quality digital resources, should also be encouraged to develop, via its users, high-quality reviews of these resources. A review process and panels comprised of teachers, administrators, curriculum developers and scientists need to be created to review these materials according to criteria consistent with DLESE criteria.

7. Encourage closer collaborations between publishers of mainstream textbooks and developers of innovative materials and technology.

Textbooks are the dominant vehicle for classroom instruction. Rather than view innovative curriculum materials as an add-on or replacement of textbooks, publishers and developers should collaborate to infuse the innovations into revisions of the textbook programs. This will create a powerful entrée for teachers who rely on the textbooks to explore alternative approaches.

8. Develop a matrix of reviewed instructional materials at each grade level for Earth and space science, mapped to National Science Education Standards/Benchmarks for Science Literacy.

In order for exemplary instructional materials to be used in classrooms, teachers, schools, and districts must know about them and they must be keyed to appropriate grade levels. This matrix should be updated annually and made available on the Web

EarthComm: Earth Science Curriculum

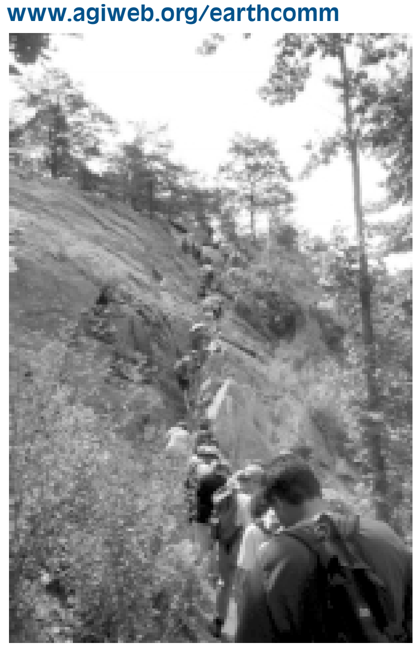
EARTHCOMM: EARTH SCIENCE CURRICULUM

Upon seeing the lack of Earth science education in the nation's classrooms, the American Geological Institute (AGI) took matters into its own hands. With support from the National Science Foundation and donors of the American Geological Institute Foundation, the AGI developed of EarthComm (Earth System Science in the Community), a comprehensive high-school curriculum in the Earth sciences that features student learning materials, teacher resources and support networks, and assessment tools for a hands-on, inquiry-driven, instructional program.

Informed by the National Science Education Standards (1995), AGI's other successful Earth science education initiatives, and key science education curriculum and reform programs, EarthComm stresses the learning of concepts and skills that enable students to bolster their critical thinking and understanding of Earth as a system. Its pedagogical strategy revolves around problem-solving, in which the teacher serves as facilitator, and it seeks to expand the learning environment to include online access to data, field work and laboratory activities.

What is EarthComm's overall goal? Nothing short of "the teaching, learning, and practice of Earth science by all students in all US high schools."

www.agiweb.org/earthcomm



EarthComm®
EARTH SYSTEM SCIENCE IN THE COMMUNITY

and in print. The matrix will include links for each item to the DLESE database of reviews so that potential users can obtain further objective information about the materials. These materials should include both commercial and non-commercial products.

9. Develop vignettes of exemplary instruction, curricula and assessment aligned with the core learning goals for Earth and space science.

In this report, we advocate substantial changes in the methods and materials that teachers use in Earth and space science instruction. To clearly convey the nature of these changes, curriculum developers, working with scientists, should develop vignettes that illustrate how these new methods and materials are used in classroom settings at grades K-4, 5-8, and 9-12. These vignettes should be produced as printed descriptions (with text and images) and as live-action videos of classroom instruction. They should be widely disseminated to state and local curriculum leaders, teachers, parents, and Earth and space science professionals. NSF or similar federal agencies should fund creation of these vignettes.

10. Develop mechanisms to create awareness of and disseminate the core learning goals, reviewed instructional materials and vignettes for K-12 Earth and space science.

The objective review of Earth and space science instructional materials, the creation of a database of these reviews, and the organization of these materials into a matrix linking them to grade levels will be of little use if practitioners do not use these resources. Therefore, mechanisms should be developed to create awareness of them. These mechanisms would include regular meetings with national, state and district leaders to inform them of the availability of exemplary materials, Web links on DLESE to the reviews and the matrix, focused mailings to curricular leaders, and distribution to NSF dissemination centers and pre-service educators. These materials should also be disseminated to textbook publishers to serve as models for future development.

Visualizing Earth: How Students "See"

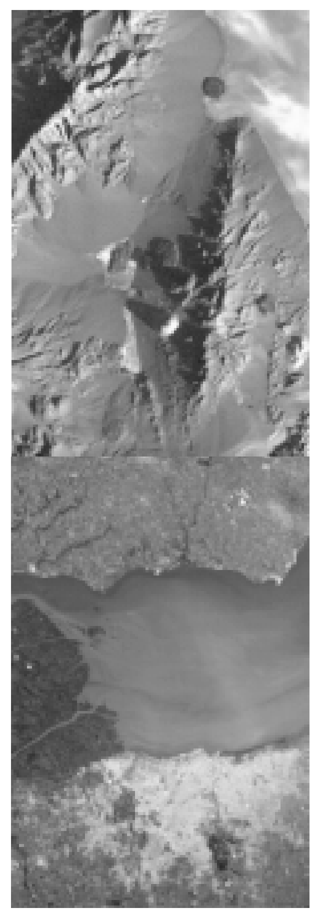
VISUALIZING EARTH: LEARNING HOW STUDENTS "SEE" SPACE-AGE IMAGERY

Visualizations and remotely-sensed images, which provide local, regional and global views of environmental systems and their interactions, empower scientists to better understand our planet. These visualizations include satellite images, Space Shuttle and International Space Station photography, and geographic information systems (GIS) data. Such space-age resources also promise to revolutionize Earth science education by offering students the same powerful perspectives of the world.

Yet while these images can be spectacular, scientists train extensively to analyze and interpret them. How do students "read" imagery and visualizations? And how can educators present these resources so students can effectively make meaning of them? These are the questions addressed by Visualizing Earth, a cognitive research project funded by the National Science Foundation (NSF) and developed and implemented by TERC, the University of California San Diego, Pennsylvania State University and San Diego State University.

Through a combination of classroom experiences, laboratory experiments and structured interviews, the project explored the cognitive underpinnings and implications of student use of geographic and space-orbit visualizations. It focused on such cognitive factors as symbolic representations of data, three-dimensional perspectives, scale, view-angle and change-over-time transformations. The curricular context for the research was plate tectonics for long-term change and weather for short-term change. The pedagogical strategy emphasized inquiry-based learning.

The Visualizing Earth project determined that visualizations and remotely-sensed images strongly interest students and enhance their learning of Earth science, although students need to learn how to "see" with these new resources in order to take full advantage of them.



1. Visualizations enable students to "see the unseeable" and better understand key science concepts.

2. In contrast to passively viewing images, students are far more engaged and learn more effectively when they can actively manipulate image and data displays and gain new perspectives.

3. Image analysis tools for classrooms can amplify learning with certain design features. When students can establish the view angle, for example, or calibrate distance, they better grasp the information inherent in images and visualizations.

4. Advanced visualization tools, when adapted to the cognitive needs of students, can make complex scientific concepts accessible and promote the building of scientific explanations.

Visualizing Earth offers educators a framework for integrating visualization resources into instructional materials and classroom education. When students work with visualizations as tools of inquiry, they can better understand key concepts in Earth science, develop skills of scientific thinking and problem solving and conduct their own investigations in Earth and its systems.

visualizingearth.ucsd.edu

VENICE, ITALY: EARTHKAM IMAGE # ISS011.ESC.36083348

Technology

Technology for a Space-Age Perspective

Technologies have revolutionized education and nowhere is this more evident than in Earth and space science classrooms. Today, students can deploy many of the same tools that scientists use, such as visualization software, geographic information systems (GIS) and even a digital camera onboard the International Space Station, to deepen their understanding of Earth and space science. The Internet can bring into classrooms scientific images and data from sources as diverse as Earth-orbit satellites, Martian probes, deepwater marine expeditions, and other schools around the world.

Technologies lie at the heart of Earth and space science. From Galileo's telescope and mapping techniques to today's remote sensing and satellite imagery, new tools enable discoverers to see and understand Earth and space more effectively. They have revolutionized Earth and space science research. Many of these same tools can drive the revolution in Earth and space science education as well.

Education technologies are strategic resources that enhance students' ability to sense, measure, question, understand, communicate and learn. They empower students to learn as active scientists rather than as passive consumers of textbook-based curricula. They enable students to learn core concepts more clearly by offering visual representations of ideas that otherwise might seem confusing or unclear. They transform science from canned labs and the passive memorization of content to a dynamic, hands-on, authentic process of investigation and discovery. By using the same technologies as scientists, students acquire vital process skills and deepen their understanding of science. Additionally, they familiarize themselves with many of the same tools and processes that they will encounter as adults, particularly in the workplace.

The use of technology in education has increased dramatically over the last decade, but many would agree that the greatest potential lies with science in general and Earth and space science in particular. The availability of tools that allow students to collect, analyze and visualize their own data, real-time data from around the world and archived data on a wide variety of topics has the potential to truly revolutionize the teaching of Earth and space science. Computers are now widespread in schools, as is Internet-connectivity in libraries, computer labs and many classrooms – even in low socio-economic districts. Inexpensive and portable instruments such as personal digital assistants (PDAs) and GPS tools allow for the quick, easy collection of environmental information from the field in a digital format. An awesome variety of images and interactive visualizations are available on the Web, enabling students to "see" phenomena remotely at scales beyond our normal senses and from archives that preserve data from times past. Furthermore, with visualization and GIS tools, students can manipulate the images and conduct sophisticated analyses and queries of freely-available tabular, spatial and image data.

The future of educational Earth and space science technologies is easily envisioned. Students will have ready access in schools, libraries and homes to a wealth of Web-based visualizations and other Earth and space science resources, linked with their textbooks and classroom curriculum. Students will use a new generation of low-cost, cross-platform portable computers, combining the capabilities of desktop computers with the functionalities of PDAs, that are small and simple enough to use for field research. Learners will attach probes to their devices to capture and store data. They will deploy easy-to-use workgroup software to wirelessly share their findings, evaluate data and prepare reports. They then will upload their data to a Web site where they can share information with students nationwide, conducting distributed experiments and collaborative investigations. The foundations for such fieldwork are already in place through such programs as GLOBE, in which schools worldwide are collecting environmental data and submitting them online for use by scientists and in their studies.

While there are many existing technology tools and programs that can take us to 2010 and beyond, several barriers hinder their effective implementation. These include:

→ money (district, state and federal funding sources are limited)

→ time (finding and acquiring effective technology can be very time intensive)

→ training (it is unrealistic to expect teachers to take time away from their teaching or to give their own personal time to be trained in the effective use of classroom technologies)

→ hardware and software (the reliability, compatibility and obsolescence of tools, computers, software, networks)

→ effective curriculum, technology and pedagogy integration

→ and technical support.

None of these barriers is insurmountable. When viewed constructively, they present a set of opportunities that can shape the future role that hardware, software and human resources will play in bringing about the most effective use of technology in Earth and space science education. Technologies have fueled both prior discoveries and the current revolution in Earth and space science and can fuel Earth and space science education.

There must be an infusion of existing resources into Earth and space science education, as well as the development of new tools designed specifically for students that use both current and emerging technologies. These tools should be readily available in all science classrooms. Most importantly, curriculum developers and science coordinators need to integrate these resources into curricula and for teacher support in deploying them in the service of learning.

Technology

Recommendations:

1. Promote widespread use of existing Earth and space science technology resources in classrooms.

There is a wealth of existing resources readily and freely available on the Web, many with associated learning activities. Many have been developed especially for education through the support of NASA, the National Science Foundation (NSF), the United States Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA) and other government agencies. In fact, the real challenge is not a deficit but a surplus of resources. Hence, other recommendations involve helping teachers to identify the most appropriate resources for their widespread use.

2. Develop mechanisms that help teachers search for and access high-quality data, tools, and activities to support effective Earth and space science learning.

The Digital Library for Earth System Education (DLESE) should be strongly supported to offer mechanisms for the user community to provide evaluations of both software applications and data sets available to Earth and space science education. Additionally, a matrix of catalog criteria that will enable Earth and space science educators to search for and access useful digital resources (e.g. subject matter, grade-level usefulness, addressing state or national standards) needs to be developed in conjunction with DLESE. Teachers should be encouraged to contribute to, as well use, DLESE.

3. Encourage technology manufacturers to develop and market a new generation of tools for student use.

Students require tools that empower them to easily collect, evaluate and share data among themselves

NASA's Earth Observatory

NASA'S EARTH OBSERVATORY: WEB-BASED DELIVERY OF THE LATEST AND BEST EARTH SCIENCE

Anyone who questions the value of the Internet as an Earth and space science education resource should visit NASA's Earth Observatory. The Web site demonstrates how Internet and visualization technologies can serve as extraordinary resources for classroom studies, teacher professional development and informal education. The site is dedicated to Earth science, providing the latest news, information and satellite imagery about our home planet. Every week, it features timely satellite photography and concise explanations of the latest discoveries in Earth science, any of which can trigger student inquiries and investigations. It offers a rich variety of reference materials on all aspects of Earth and space science, including remote sensing, geoscience pioneers and NASA missions. It provides datasets that users can graph and display with animations, dynamically revealing how key environmental parameters vary over the planet and change over time.

Subscribe to Earth Observatory, which is free, and receive a weekly e-mail announcing the latest images and news culled from NASA satellites, encompassing the full scope of Earth and space science.

www.earthobservatory.nasa.gov

and peers elsewhere. For example, an ideal means for students to collect data in the classroom, in the field and at home would be small, low power, low-cost notebook computers that integrate the functionalities of handheld, wireless and desktop computing devices. They would allow students to attach various probes to gather, store and communicate data. Such innovative devices would work with both Macintosh and Windows environments, and would be durable, easy-to-use and cost-effective. When they are coupled with collaborative software that integrates basic word processing, spreadsheet, database, graphing and communication functions, students would be able to conduct authentic, distributed investigations into Earth and space science as well as other disciplines.

These classrooms tools should be:

→ low cost – Regardless of how effective technologies may be for learning, they must be affordable for schools. Additionally, manufacturers should not offer frequent updates for their products, which will eliminate short-term obsolescence and reduce pressure on school budgets.

→ durable – Tools must withstand the rigors of both classroom and field use.

→ reliable – Technologies must be dependable, reducing costs for their maintenance or replacement.

→ easy-to-use – Classroom tools must be simple to use at their designated grade levels for both students and teachers.

→ supported by learning activities – Every tool should be bundled with learning activities that prepare both students and teachers to use the device properly.

→ standardized – As in professional science, tools must be standardized to support the sharing of real science data.

→ multi-functional – Tools should support a variety of capabilities for use in many disciplines.

All stakeholders should encourage software and hardware manufacturers to develop such innovative learning technologies.

4. Develop mechanisms for more widespread integration of technology into professional-development workshops.

The availability of technologies in classrooms does not ensure they will be used; teachers require preparation to deploy them effectively. A strong grass-roots effort should be promoted to implement workshops that integrate content, pedagogy and assessment with appropriate uses of technology. These workshops should utilize the expertise from local/regional sources like education, industry, universities and government. This strategy could be best achieved through the creation of state alliances that will serve as collectors and repositories of information on (1) who is available for conducting workshops; (2) specific workshop offerings; (3) the effectiveness of various workshop types and formats; (4) the needs for locally relevant data; and (5) ways to encourage the creation of new activities from within the corps of practicing teachers.

Developers within industry and education should produce technology-training support tools on a variety of media (Web-delivery, CD-ROM, DVD, videocassette). Such tools should illustrate how to operate computer tools (functionality), as well as how such tools might best be used within an educational setting (pedagogy) to enhance specific learning goals (content).

5. Support the development of a strengthened technology infrastructure.

There is a real need for equity in hardware, software, networking and technical support in Earth and space science education. All Earth and space science teaching environments require reliable, high-speed network connections and increased access to technological tools. These include networked computers, PDAs, GPS, analytical and visualization software, as well as laptops available to both teachers and students for use at home. Furthermore,

Students Photograph Earth from Space

ISS EARTHKAM: ENHANCING EARTH SCIENCE WITH SPACE-AGE PERSPECTIVES

The 20 students at Brunswick Junior High School in Brunswick, ME, trained well for their mission with the International Space Station (ISS). Working as a team, with each student having his or her own responsibilities, they learned to identify targets and communicate them to the ISS. On October 9, 2001, they brought sleeping bags and munchies to the school's library and set up a Student Mission Operations Center (SMOC). For the next 24 hours, they directed a digital camera onboard the ISS in photographing deserts, volcanoes, cities, weather patterns and other features of Earth.

These students were participating in ISS EarthKAM, an innovative NASA program that empowers middle-school students to learn about Earth and to direct an Earth-pointing camera in space orbit. Originally, the camera was mounted in the Space Shuttle, where it was available only during Shuttle missions. Now it resides in the ISS and is available more often, increasing the program's scalability.

ISS EarthKAM illustrates how advanced technologies, like visualizations, image analysis tools, the Web and the ISS, can enhance classroom education. EarthKAM's imagery enables teachers of such disciplines as Earth science, geography, meteorology, mathematics, history and social studies to enhance curricula and add a vital dimension and timeliness to content.

Initiated in 1994 by Dr. Sally Ride and other partners, EarthKAM is funded by NASA and is operated by a partnership between the University of California at San Diego, NASA, the Jet Propulsion Laboratory in Pasadena and TERC.

And what did the students in Brunswick photograph? They selected sites ranging from such natural features as the Himalayan Mountains and the Amazon, Ganges and Mississippi rivers to human developments like the Great Wall of China and, yes, Disney World. They selected these sites as part of student-defined investigations in a variety of topics in Earth science and human geography.

www.earthkam.ucsd.edu/

trained support staff is needed to maintain the effective operation of technology tools, and formal mechanisms must be implemented to regularly update and replace technological tools. For these reasons, sufficient resources must be invested on local, state and federal levels into schools' technology infrastructures.

6. Support teacher mentoring and communications through collaboration.

Professional mentoring and partnerships offer powerful opportunities to support teachers' use of classroom technologies. To this end, either existing state-level Earth and space science organizations, or new ones created for this purpose, should develop lists of Earth and space science technology users (from K-12 education, industry, university, and all levels of government). Drawing from these available technology experts, collaborations with Earth and space science teachers can be established to promote the use of technologies that are common within the practicing community. Moreover, future grants and contracts for Earth and space science should incorporate built-in mechanisms that encourage work leaders to collaborate with teachers, going so far as to having teachers included as staff.

7. Develop a stable funding mechanism to support the effective application of technology in Earth and space science education.

Although implementation of technology enhancement programs is best done at the local and state level, funding needs to come from the federal level or there will be uneven success across the country. Congress should fund an Educational Technology Grant Consortium for states, based in part upon the model of the Space Grant Consortia. Also, industry partners, as well as state and local governments, should provide financial and technical assistance to this effort. There should be policy changes in state and federal contracts and grants for science that would require a percentage of the funding to be devoted to education service. The funds generated through this effort could be directed down to schools through state mechanisms, such as state alliances, and be used to support technology acquisition and teacher training.

9. Promote partnerships among schools, universities and research labs to continually evaluate the effective use of technology in Earth and space science education.

A sound research base is needed to ensure that training for teachers and the subsequent classroom use of technological tools is effective. Researchers must develop adequate instruments to assess technology tools and their application in the classroom. Funding mechanisms will be needed to implement these emerging research designs. Finally, the results of such studies should serve as guides to modify and enhance classroom-teaching strategies centered on the use of technology, and the design of teacher technology enhancement training programs.

The GLOBE Program

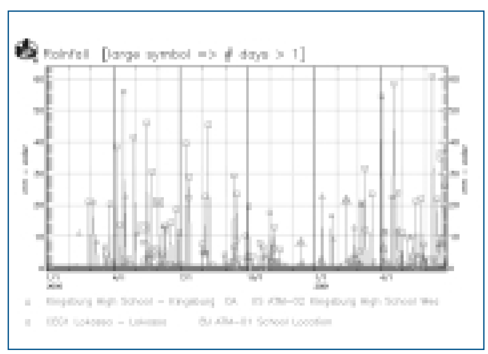
GLOBE: AUTHENTIC PARTNERSHIPS BETWEEN STUDENTS & SCIENTISTS

Every day across the planet, students measure environmental parameters and submit their findings to databases on the Web. Scientists then access the data to support their investigations. This initiative is the GLOBE (Global Learning and Observations to Benefit the Environment) program and it is the realization of what was once a pipe dream for educators – scalable but authentic partnerships between students and scientists. Such opportunities allow students to understand science through hands-on experiences, learning that science is a rigorous but rewarding process for acquiring knowledge.

Since 1995, GLOBE has engaged a million K-12 students in over 10,000 schools worldwide in data collection and observations. They work in teams, coordinate activities and peer review their work. When sufficiently skilled to collect science-grade data, they submit their findings to GLOBE databases, where the data are available online to students, scientists and the public.

Students use the data in Earth science classes to study the environment locally, globally and over time. GLOBE provides students with tools to gather, graph, analyze and submit data, prompting math teachers to join the program. Students acquire the rigors and ethics of science, like standardization, peer review, collaboration and sharing. GLOBE is sponsored by the NSF, NASA, NOAA and the EPA along with over 140 colleges and universities, state and local school systems, and non-government organizations.

www.globe.gov



BANGLADESH AND THE BAY OF BENGAL: EARTHKAM IMAGE # STS081.ESC.00212933

Assessment

Assessment and Evaluation

Long fundamental components of K-12 education, assessment and evaluation are vital to improving programs, teaching, and learning. In this report, assessment is defined as the collection of information about student achievement and performance. It includes formative (ongoing and embedded) and summative (end of term or large scale) components. Evaluation in this report refers to the data collected to determine the effectiveness of large-scale and long-term programs in guiding Earth and space science education reform. The goal of these long-term evaluation efforts is to improve classroom, district and organization practices and policies to promote enhanced student achievement.

The reform of assessment is a critical component of the revolution in Earth and space science education. Most states have some form of annual assessment of student learning, and the movement towards assessment and accountability is growing. The nature of each state's assessment is a strong force in defining and shaping a state's priorities. Hence, we need to ensure that Earth and space science is included in science assessments at all appropriate levels.

A second priority is to make sure that the nature and content of the assessments match the emerging new curriculum priorities. The content should encompass the major domains of Earth and space science, such as geology, meteorology, oceanography and astronomy. As a central theme, it should feature Earth as a system as well as other related unifying concepts and processes. Assessment should involve the skills of inquiry and investigation, including the use of remotely-sensed, visualizations and other tools of technology.

Unfortunately most state assessments focus primarily on memorized facts and vocabulary, typically using formats such as multiple choice and short-answer questions. While these have value in assessing factual content knowledge, they generally do not tap the deeper goals of science education that we deem crucial. For example, although "science as inquiry" is a major focus of the National Science Education Standards, traditional tests typically do not assess inquiry and problem-solving skills. Similarly, although remotely-sensed images and visualization technology are essential tools of Earth and space science and enable students to more clearly understand its core concepts, visualizations are rarely, if ever, used in traditional tests. Also, the concept of Earth as a system, now regarded as the central paradigm in Earth and space science, is typically tested at the component and process level with only minimal attention to the critically important interconnections among these components. Hence, the Earth and space science education community should develop and promote assessments that measure the skills and understandings central to the educational reform we envision. These assessments must go beyond traditional assessment, encompassing a richer and deeper view of Earth and space science learning.

We recommend a greater emphasis on performance-based assessment, which can complement or supplant traditional testing. Performance-based assessment forces students to demonstrate and apply their learning in deeper contexts. Giving students opportunities to "show what they know" in real contexts is one of the most authentic forms of assessment and one of the best measures of student mastery.

> "[Performance-based] assessment exercises require students to apply scientific knowledge and reasoning to situations similar to those they will encounter in the real world outside the classroom, as well as to situations that approximate how scientists do their work." (NSES, NRC 1996)

Such performance-based assessments also serve as rich resources for classroom teachers to better understand what their students have learned and how they can apply their knowledge and skills in practical and real-world contexts. Such assessments are especially important given the increasing emphasis on educational accountability.

Assessment
Recommendations

1. Each state should review its science assessment tests to ensure that Earth and space science is included at elementary, middle- and high-school levels, and that the test items align with the state's curriculum priorities.

Almost all states have a program for annual assessment of student progress. However, these annual assessments are generally for reading, writing and mathematics. Science may be included but not typically on an annual basis. These assessments should be reviewed to make sure that Earth and space science content is included at all appropriate grade levels. Also the nature and content of these assessments should be reviewed to ensure that there is a close match between the assessed content and the curriculum priorities. This is especially important for the underlying theme of Earth as a system, science as inquiry and the use of remotely-sensed images and other visualizations.

2. Review and analyze Earth and space science related test items on NAEP, TIMMS and other widely used standardized tests to clarify which core concepts and skills in Earth and space science are measured and which are not.

The National Assessment of Educational Progress (NAEP) is a set of widely-used national tests, including science tests at grades 4, 8 and 12. NAEP is administered every two years, with the results summarized in the "Nation's Report Card." The 1995 Third International Mathematics and Science Study (TIMMS) and the 1999 TIMMS-Repeat assessed student learning in science (and other subjects) in the US and in about 40 other countries around the world. In each case, the results were used to assess the quality of science education and aggregate levels of student performance. Given this importance, we need to better understand these instruments in terms of the specific Earth and space science content and skills assessed in the test items. Such an analysis will help us understand the potential strengths and limitations of these instruments for monitoring progress in the new aspects of Earth and space science education that are advocated in this report, such as science as inquiry, Earth as a system and the use of visualizations.

3. Develop and disseminate a national database of high-quality Earth and space science assessment items, along with tools to help educators and administrators evaluate their own Earth and space science education reform efforts.

A national body of scientists and educators in Earth and space science education should create a databank of assessment items organized so teachers and others can construct high-quality measures of student achievement. This database should include not only good multiple-choice and constructed response items but exemplary, performance-based assessments and scoring rubrics for elementary,

Science Monthly: Keeping Teachers Up-to-Date

SCIENCE MONTHLY: E-MAIL NEWSLETTER KEEPS SCIENCE EDUCATORS UP-TO-DATE

The National Science Teachers Association (NSTA) and Learning Network illustrate how partnerships can leverage available resources to improve Earth and space science education. The organizations formed a strategic partnership to produce a monthly e-mail newsletter called Science Monthly. The theme-based newsletter will provide K-12 educators with timely activities, lesson plans and resources for quality science instruction. The first issue of Science Monthly centers on the theme of animal adaptations, with subsequent issues focusing on such topics as nutrition, classroom safety, careers in science, soil, Earth Day, summer solstice and assessment.

This project offers the partners an opportunity to leverage their extensive resources and Internet capabilities. NSTA is gathering lessons plans and activities from its rich archives as well as from books produced by NSTA Press, the publishing arm of NSTA. Learning Network will also provide content for the newsletter.

Additionally, Science Monthly will be published during the summer months, enabling teachers to plan special projects prior to the school year. One month's theme, for example, was community partnerships, which offers teachers ideas for building relationships in the community that can support classroom instruction. Science Monthly is e-mailed on the third Wednesday of every month and is available free to teachers who sign up.

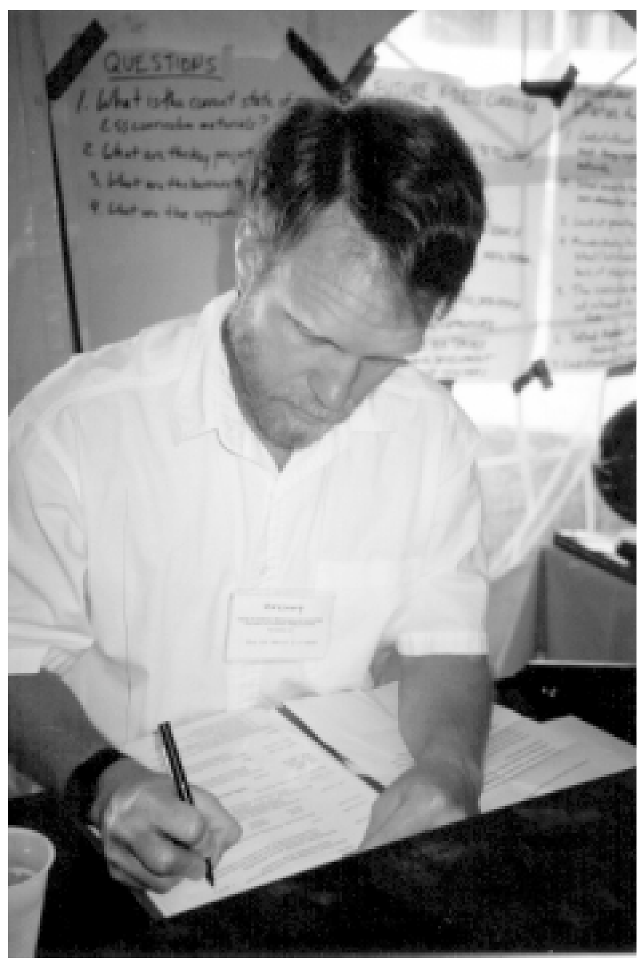
www.teachervision.com/tv/lounge/newsletter/science-signup.html.

middle and high school. These assessments should measure student learning of the core concepts and skills identified for Earth and space science in the National Science Education Standards and Benchmarks for Science Literacy (see recommendation 4 in the Curriculum section of this report, which calls for the development of such core learning goals). These assessments should be developed by specialists in science assessments, and reviewed by scientists and educators. They should be carefully field-tested and revised before dissemination. Special attention should be given to the development of assessments that address the needs and assess accurate understanding of diverse student populations, including persons with disabilities, different learning styles and cultural backgrounds. These next-generation assessments should call on students to: make use of prior knowledge; synthesize information with their understanding of relevant concepts; apply understandings; develop and test hypotheses; and interpret visual, numeric and graphic data.

These assessments should be readily available for large-scale use and by classroom teachers of all levels. The Web offers an ideal way to disseminate them and the Digital Library for Earth System Education (DLESE) should serve as the clearinghouse. Web dissemination also enables the assessments to feature the types of visualization resources (images and animations) that are central to our learning goals, and allows for interactive assessments of a deeper nature than are possible with pencil and paper. Internet access has become increasingly common in Earth and space science classes. Hence, Web-based assessments in high-school Earth and space science are not only feasible, they are essential for supporting and evaluating effective student use of the visualization technology and Web-based investigations that are central to Earth and space science education reform. Also, Web distribution enables field-testing to be on larger-scales and more cost-effective than would be possible with hard-copy materials. Some of the assessments should also be available to download and print so students can do the activities when they lack convenient access to computers.

4. Foster collaborations between Earth and space science educators and other science, mathematics, geography and language arts educators to develop new assessments that promote learning across the curriculum.

Earth and space science is an integrative field that offers wonderful opportunities for cross-curricular ties with such disciplines as mathematics, geography, social studies, history and even literature. Earth and space science educators should work with their peers in these fields to develop assessments that measure interdisciplinary learning among students.



5. Provide opportunities for practicing and pre-service teachers to learn how to assess student learning effectively and identify student misconceptions.

For educational reform within the domain of Earth and space science to succeed, teachers need to understand how to assess student performance in inquiry-based learning, how to write assessments and score assessment items, and use assessment results to improve classroom practice. In addition to making assessment tools and resources readily available to teachers, efforts should be made to train teachers on new assessment strategies and techniques that go well beyond the traditional testing of students' acquisition of content. Teachers must learn how to assess students' development and use of such key skills as problem solving, critical thinking, self-directed investigations and deploying advanced tools and resources. Stakeholders should support the implementation of professional development initiatives like workshops, distance-learning, study groups, action research, mentoring and other approaches that empower teachers to fully assess student learning within new curricular frameworks. This strategy should also help teachers to identify and correct common misconceptions held by students of Earth and space science.

6. Support research on student learning of Earth and space science concepts.

To refine pedagogical strategies in Earth and space science classrooms, educators must understand how students learn key Earth and space science concepts and how their understanding can be measured effectively. Research areas should include how student misconceptions arise, the use of visualizations and other technologies to enhance learning, how different types of assessments may bolster or hinder student learning, and comparison of apparent differences in student learning (e.g. the achievement gap) demonstrated by different student populations.

RIO, SALADO, ARGENTINA: EARTHKAM IMAGE # STS086.ESC.08162147

Teaching

Professional Development and Teacher Preparation

After extensively reviewing the condition of science and mathematics teaching in America, the National Commission on Mathematics and Science Teaching for the 21st Century, chaired by Senator John Glenn, found the quality of math and science education in America to be "unacceptable." In what is known as the Glenn Report, the commission concluded that "the most powerful instrument for change, and therefore the place to begin, lies at the very core of education—with teaching itself." It adds "that the way to interest children in mathematics and science is through teachers who are not only enthusiastic about their subjects, but who are also steeped in their disciplines and who have the professional training—as teachers—to teach those subjects well. Nor is this teacher training simply a matter of preparation; it depends just as much—or even more—on sustained, high-quality professional development." Improvement of Earth and space science education depends equally on the improvement of teaching through high-quality professional development.

The Glenn Report defines professional development as sustained educational processes that enable teachers to "(1) deepen their knowledge of the subject(s) they are teaching; (2) sharpen their teaching skills in the classroom; (3) keep up with developments in their fields, and in education generally; (4) generate and contribute new knowledge to the profession; and (5) increase their ability to monitor students' work so they can provide constructive feedback and appropriately redirect their own teaching."

Of all the K-12 science disciplines, Earth and space science is in greatest need of new professional development strategies. There is inadequate success in recruiting and retaining teachers and many who teach Earth and space science are unqualified or under-qualified. Many lack sufficient familiarity with the concepts and content, and are untrained in pedagogical strategies such as inquiry-based learning. Most cannot adequately apply textbook concepts to the real-world community and region in which they live. They often lack experience with new and evolving technology learning resources, such as Web-based data and imagery.

To improve Earth and space science education in K-12 classrooms, there is an urgent need to enhance the preparation and professional growth of the discipline's teachers. Beginning with their pre-service training and extending throughout their careers, teachers require systemic, comprehensive and ongoing professional development programs and opportunities.

The following goals should guide the development of next-generation professional development programs for Earth and space science education:

- Teachers gain an extensive knowledge of Earth and space science, including such key concepts in Earth and space science as understanding Earth as a system of interlinked processes, and the application of concepts to geographic regions familiar and relevant to their students' lives.
- Teachers understand through both training and experience the most effective pedagogical strategies. These include inquiry-driven learning, field-based studies and collaborative tasks. Teachers should be able to motivate and empower students to design and conduct their own investigations.
- Teachers understand and can deploy in classroom settings the tools and resources that increase student learning in Earth and space science education. These include visualization applications and a wealth of Earth and space science data and imagery available on the Web.
- Teachers become lifelong learners, continually enhancing their knowledge and skill sets through professional development. They stay abreast of new tools, technologies and pedagogical strategies as they become available.
- The teaching of Earth and space science is aligned with state standards.
- All stakeholders in the educational system, from teachers, school administrators and institutions of higher education to professional associations, parents and lawmakers, support teacher professional development and understand that it is critical to the effective teaching of Earth and space science, as well as other disciplines, in our nation's classrooms.

Professional Development
Recommendations

Many of our recommendations build upon those offered by the Glenn Commission.

1. All states should evaluate the state of Earth and space science education in their K-12 classrooms to determine if teachers' professional development needs are being met.

States should comprehensively assess professional development support for Earth and space science teachers on a district level. The initiative should examine the scope and quality of Earth and space science education that is offered to students and the resources that are available to teachers. These include curricular materials, texts, assessment strategies, Internet access and other tools. The assessment also should consider the abilities of teachers to deploy new learning technologies such as data visualizations. By determining the state of Earth and space science education and the needs of teachers, stakeholders can develop action plans to provide adequate professional development to ensure routinely high-quality teaching and learning.

2. State departments of education should collaborate with their school districts to develop summer professional development programs for Earth and space science teachers, and federal and state funding agencies should support the establishment of professional development summer institutes for them.

For many teachers, participating in concerted professional development during the school year is not practical due to scheduling constraints. Therefore, funding should be made available to compensate teachers who invest one month each summer in professional development activities. Such a strategy will provide teachers with the time necessary to enhance their knowledge of content, gain training with pedagogical strategies, bolster their skills with technologies and tools, and learn the latest advances in the discipline. By institutionalizing professional development in their lives, teachers greatly refine their skills and serve as role models for lifelong learning.

Professional development summer institutes will provide teachers with annual opportunities to enhance their knowledge of Earth and space science content, learn new teaching skills, and gain experience in deploying technologies in their classrooms. Their faculties should consist of teachers who are experienced with the best practices in Earth and space science education. The institutes can provide both onsite training at school facilities as well as online mentoring, guidance and resources.

3. Federal and state departments of education, as well as the NSF, NASA, and other Earth and space science organizations and funders, should support and expand collaborative efforts for teacher professional development.

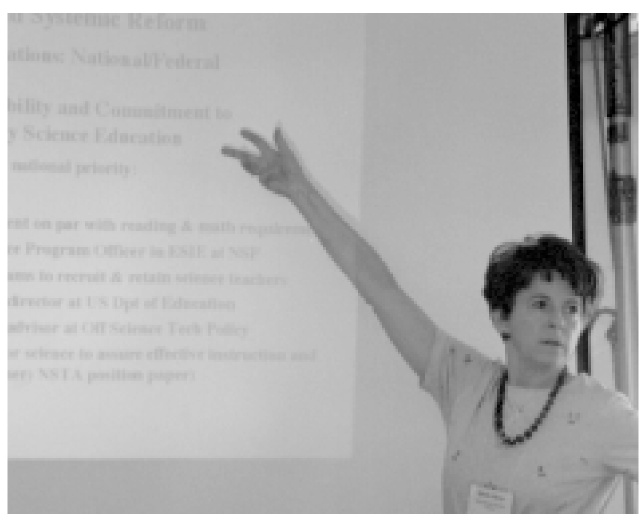
At local, state and national levels, collaborations of scientists, educators, businesses and government agencies should work together to support teacher professional development. Such collaborations enhance the teaching of Earth and space science education by facilitating communication and coordination among Earth and space science organizations.

As an example, the Coalition for Earth Science Education (CESE) is an informal union of science, education and government organizations involved in Earth and space science education. CESE can help as a coordinating body for Earth and space science education reform.

Collaborative efforts at local, state and national levels can help ensure the deployment of systemic professional development initiatives for states and school districts, monitor their progress and enable school districts to align their professional development initiatives with state curricula, teaching guidelines, performance standards and assessment frameworks.

4. State and federal funders of Earth and space science education should support the creation of communities of practice for Earth and space science teachers on school and district levels.

Local and regional communities of practice provide venues for teachers to improve their subject knowledge and teaching skills. By engaging in ongoing professional development dialogues and activities, they can mentor and learn from each other, effectively disseminating best practices and curricula materials to classrooms. For teacher convenience, these communities can be both district based and virtual, relying on Web resources and listservs for communicating and sharing resources.



5. Federal agencies, in concert with state and local resources, should implement a national campaign to recruit Earth and space science teachers.

To address the shortage of high-quality Earth and space science teachers, an aggressive multi-faceted campaign needs to be implemented to recruit sufficient numbers of trained and qualified teachers. Such a campaign can include the following initiatives:

- an outreach program to undergraduate departments of Earth and space science, geology, meteorology, environmental science, chemistry, physics and biology, encouraging their graduates to consider teaching as Earth scientists;
- an outreach program to Earth and space science professional societies, encouraging members who are interested in transitioning to teaching. Members also can participate in mentoring programs for pre-service and in-service teachers and support an outreach program at colleges and universities to encourage teacher recruitment;
- a national outreach media campaign, supported by the federal government, to attract young people to teaching careers in Earth and space science;
- funding for loans and scholarship programs through appropriate federal agencies to support the induction of teachers into Earth and space science education, particularly teachers from underrepresented groups;
- the development and dissemination of materials and information as a nationally coordinated effort to stimulate recruitment for both mid-career and recent college graduates.

6. The federal government should fund the development of Earth and space science teaching academies.

These academies will provide one-year, research- and school-based preparation programs for recent college graduates and persons seeking rewarding mid-life career changes, as well as in-service Earth and space science teachers who seek to enhance their skills and professional status. Students will receive in-depth training in Earth and space science and advanced classroom teaching strategies and methods. Additionally, federal funds should be made available to enable school districts to hire available graduates as Earth and space science teachers. Rather than invest in new brick-and-mortar facilities, each academy will be operated under the auspices of existing educational institutions and have a strong distance-learning component so that professional development can occur throughout the year.

7. Local, state and federal organizations should work with businesses to form business/school district partnerships.

Businesses, particularly those that rely on Earth and space science, can play vital roles in teacher professional development, providing expertise, funding, materials and equipment to enhance teaching and encourage students to pursue Earth and space science as a career path. Business partnerships can provide laboratory and data-gathering tools and train teachers on classroom technologies. They can support teacher communities of practice by hosting professional development Web sites for local teachers. They can provide employees with “release time” to mentor Earth and space science teachers and support classroom learning. They can offer paid summer internships within their organizations for teachers to enhance their skills.

The Coalition for Earth Science Education (CESE) and others involved in this field should work with businesses and their professional organizations, such as the National Alliance of Business and the Business Coalition for Education Reform, to offer models of existing partnerships and encourage new ones. Special attention must be paid to the fact that not all districts have a significant business base. As a result, mechanisms must be developed to ensure professional development support for these localities as well.

8. Federal agencies should further fund the Digital Library for Earth System Education (DLESE) to support additional professional development resources.

DLESE provides a central clearinghouse for digital information, curricula, data and visualization tools for Earth and space science education. This important initiative also establishes ongoing forums for scientists and educators to collaborate on designing and developing online resources. The expansion of DLESE should include a Web portal dedicated to the professional development of Earth and space science teachers. This portal will link teachers to Earth and space science content and resources, lesson plans, and video examples of the best teaching practices. It also will feature an online professional journal for Earth and space science teachers, enabling them to publish research and share teaching strategies, as well as online resources for synchronous and asynchronous conversations, meetings and idea sharing.

SAUDI ARABIA: EARTHKAM IMAGE # STS081.ESC.01002957

Partnerships and Collaboration

In considering the essential role of partnerships and collaborations in the revolution in Earth and space science education, it is interesting to reflect on Earth itself as a model of "partnerships." The concept of Earth as a dynamic system of interacting components and processes has become the dominant model for understanding our home planet in its full complexity. The geosphere, hydrosphere, atmosphere and biosphere all interact in myriad ways. For example, energy from the sun (exosphere) warms the oceans (hydrosphere) and causes evaporation of water. Clouds and wind (atmosphere) transport water and energy onto the continents. Mountain ranges, built by the slow movement or Earth's tectonic plates over millions of years (geosphere), intercept these weather systems causing rain and snow to fall. The resulting precipitation erodes the mountains, nourishes the soil and provides vital sustenance to numerous plant and animal species (biosphere). As mountains rise and fall, weather patterns change and species evolve or go extinct in response to changes in their environment.

So too do the components of the revolution in Earth and space science education necessarily interlink into a whole. New technologies enable innovative teaching strategies and curricula. This, in turn, requires teacher professional development, supported by policy reform and monitored by new forms of assessment. Such interactions require coordination, collaboration and partnerships on multiple levels. The challenges are too large to be resolved by individuals and organizations working in isolation. We all need to identify and share resources, coordinate implementation and reform efforts, create synergies, and work toward common goals.

As an example of an active partnership in this field, the Coalition for Earth Science Education (CESE) is an informal group of organizations involved in Earth and space science education. Members include: educational organizations such the National Earth Science Teachers Association (NESTA) and the National Association of Geoscience Teachers (NAGT); science organizations like the American Geological Institute (AGI), the American Geophysical Union (AGU), the National Center for Atmospheric Research (NCAR); and such federal agencies as NASA and the United States Geological Survey (USGS). CESE was formed when the National Science Education Standards were being developed to provide a useful and cohesive voice to help shape the Earth and space science component of the standards. CESE continues to meet regularly to coordinate efforts of the member organizations and it was instrumental in defining and shaping the National Conference on the Revolution in Earth and Space Science Education.

Expanding from this base, the Earth and space science education community should strengthen its ties to other fields of science education, such as physics, chemistry and biology. Our efforts to promote our field should be integrated within the larger effort to promote science education reform in general. As an example of inter-disciplinary collaboration, experts in physics, chemistry and biology education participated in the Revolution Conference. We also have opened conversations with the geography education community, especially in viewing the state-based Geography Alliance program as a role model for similar efforts for Earth and space science education.

Partnerships between Earth scientists and educators are also essential. Such partnerships can help ensure that the Earth and space science content and resources used in schools are accurate, up-to-date and relevant. Scientists can benefit from such partnerships by a stronger connection to students, teachers and the general public. Such projects as GLOBE, Jason and River Watch engage students with scientists in authentic research projects like monitoring environmental variables in study sites near schools and providing the data to scientists.

Thousands of providers of informal science education and outreach—museums, science centers, planetariums, national parks, libraries, education television and many others—produce materials and programs for formal K-12 Earth and space science education. They often have access to physical materials, technology and facilities that can help classes better reach science standards and better expose students and their teachers to applications in the real world. They sit at the interface between cutting-edge scholarship, the general public, and formal education, specializing in communicating age- and background-appropriate information about technical subjects. They can serve an effective interface between the K-12 education community and the scholarship coming from the research of academia and industry.

Partnerships can also produce innovative instructional materials. Due to the long lead-time for textbook production and the infrequency of new textbook adoption, textbook content is often outdated by five or more years. As a result, teachers supplement student readings and work with materials from other resources such as the National Science Teachers Association (NSTA), the Smithsonian's National Science Resources Center, professional and scientific societies, government agencies and articles from newspapers and journals. These projects are typically the collaborative work of educators, scientists and editorial staff and are often the innovators in curricular reform. Working outside the constraints of textbook production and adoption, they can introduce new concepts and up-to-date content in a timely manner.

Another example of an important partnership is the National Science Foundation (NSF)-funded Digital Library for Earth Systems Education (DLESE). This multi-institution effort serves as a central gathering point and clearinghouse for Web-based resources—data, lesson plans, visualization tools, curricula, assessment materials and other resources. Throughout this conference report, recommendations support the use of DLESE as an existing clearinghouse.

Partnerships and Collaborations Recommendations

1. At the state level, establish alliances to promote Earth and space science education reform.

States are a critical focus for educational change. States establish curriculum frameworks, define assessment procedures, support teacher professional development and institute other reform efforts. Hence, there should be a nationally coordinated program of state-based alliances for Earth and space science education reform. The alliances should include a broad range of stakeholders, such as state departments of education, scientists, teachers, businesses, professional societies, informal education organizations, and government agencies like NASA, the USGS and the National Oceanic and Atmospheric Administration (NOAA). Using a model that has been well established by the geography education community's Geographic Alliances program, such state-based alliances should serve as catalyzing forces for reform in each state.

2. At the national level, encourage organizations and businesses to join the Coalition for Earth Science Education (CESE) and support coordinated reform efforts.

CESE is an informal coalition of education and scientific organizations involved in Earth and space science education. With its eight-year history and diverse membership, it has emerged as the de facto coordinating coalition through its yearly meetings. This role should be acknowledged and used to build synergy and coordinate communication among its members. Other organizations should be encouraged to join. However, members attending CESE meetings have vocally expressed their opinion that CESE should not have the goal of becoming an institution in itself with staff, funding or operational responsibilities. There are other organizations that fulfill this role. Rather, meeting attendees have maintained that CESE as an independent entity is ideally situated to help coordinate and encourage efforts by its member organizations through regularly scheduled meetings and communications.

Coalition for Earth Science Education

COALITION FOR EARTH SCIENCE EDUCATION: COLLABORATING TO IMPROVE EDUCATION

The Coalition for Earth Science Education (CESE) functions on the assumption that voices can be heard more effectively when speaking in unison than when speaking independently. In early 1991, representatives of some twenty societies, organizations and educational institutions involved in Earth Science education attended a series of informal meetings to create a means for speaking with a unified voice on critical issues related to science education reform. From these meetings, CESE emerged as a loose confederation of individuals representing the science educational efforts of various government agencies, professional societies and college/university centers of science education.

CESE describes its purpose as: "For the first time, to bring together the combined forces of the Earth Science community—societies, organizations, government, industry and educational organizations—a dedicated group of 1.4 million Earth scientists and Earth science teachers. To facilitate communication, cooperation, and coordination among Earth science organizations — geologic, astronomic, hydrologic, atmospheric, and oceanographic—on education activities, and to provide a united voice on national and regional policy issues which affect Earth Science education reform."

The coalition seeks to put Earth science on parity with other sciences and to enhance Earth science literacy. To this end, it works to ensure the quality of the field's educational materials and uses the influence and collective voice of its members to address issues of concern to the Earth science education community. CESE sponsors annual meetings open to anyone with an interest in Earth and space science education and actively promotes collaborations among members. The Coalition also sponsors an Earth and space science mega-booth at National Science Teachers Association annual convention that brings together the many resources developed by its members.

www.ceseweb.org

3. The professional Earth and space science teaching associations should explore unification and collaborations with other science and education groups.

The NAGT, NESTA and the National Marine Educators Association (NMEA) are three of the primary organizations of Earth and space science teachers. While they have developed somewhat different areas of focus, in reality there is far more that is in common. They should explore unification and work with astronomy and atmospheric science education groups to present a unified front for reforming Earth and space science education and supporting the member teachers. In addition, Earth and space science educators should build strong collaborations with biology, chemistry, physics, geography and other disciplines to support science education reform across the curriculum, at all grade levels.

4. Promote partnerships for initiatives in teacher preparation, professional development and ongoing classroom support.

Teacher training and support is one of the most important aspects of school reform. As detailed in the Professional Development section of this report, efforts in this regard need to include scientists, educators, colleges, universities and others actively involved in working with teachers. It is critical that education departments, Earth and space science departments and other science departments work together closely in pre-service teacher education programs to ensure that students receive both the pedagogy and the science necessary to carry forth the revolution.

5. Promote partnerships among scientists, teachers, and students—especially in authentic research partnerships.

Earth and space science offers a wide range of opportunities for scientists to work with teachers and students. In the GLOBE program, for example, students worldwide collect environmental measurements that scientists use in their research. NASA's summer programs and others enable teachers and high-school students to do field research with scientists during school vacations. Such partnerships in authentic research offer powerful opportunities for student learning, teacher professional development and science research.

6. Encourage partnerships among publishers, curriculum developers, educators and scientists to infuse new approaches and resources into traditional Earth and space science programs.

Earth and space science teachers typically use textbooks as the central resource in their classrooms. Developers of innovative curricula and new technologies should be encouraged to collaborate with textbook publishers to infuse new materials and methods into the textbooks and support the use of these resources by large numbers of teachers.

7. Encourage partnerships between college and university departments and professional societies to support acceptance of Earth and space science courses as laboratory science for college admission.

Scientific societies, such as AGU and the Geological Society of America, and professional associations like NESTA, NAGT, and NMEA are the membership organizations to which many college and university faculty belong. These groups should collaborate with their memberships to ensure that high-school Earth and space science courses are acceptable for college admission credit. Such an effort would acknowledge the value of high-school Earth and space science courses and increase the number of students selecting them. Guidance counselors should be informed of progress in this regard so that they can be active allies in promoting student participation in Earth and space science courses.

8. Encourage partnerships among community-based organizations, science museums, scientists and educators to: support Earth and space science education outside of traditional school environments; enrich in-school education; and create synergies at the interface of informal and formal education.

Science museums, community organizations and public media offer outlets for education that foster self-driven learning motivated out of personal interest and curiosity. These settings reach the general public, students and their teachers, community groups and many others. Collaborations drawing on the multifarious strengths of this diverse set of educators and audiences promise to reach more people in innovative ways. Active scientific and education researchers should play a key role in these partnerships, particularly in maintaining and translating the latest scholarship. Because this is the primary channel through which adults come into contact with science, and through which school-age children can choose their own areas of science learning, such partnerships offers a mechanism for creating and maintaining a science-literate citizenry. An educated and interested public is among the best means for achieving reform in Earth and space science education.

9. Encourage partnerships for parental involvement

Parents are crucial to the success of education reform. Partnerships should inform parents about reform efforts and support their involvement. Parents can hold school administrators responsible for curricula that provide their children with the best educational practices and content. Publishers, curriculum developers and teachers should develop activities that enable parents and students to work together on Earth and space science education in the home and make it part of home learning culture.

Digital Library for Earth System Edcation

THE DIGITAL LIBRARY FOR EARTH SYSTEM EDUCATION: A NATIONAL RESOURCE

The Digital Library for Earth System Education (DLESE) is a premier Earth and space science education resource. Funded by the National Science Foundation, it is a community-based digital library project that supports inquiry-based learning in Earth science education at all levels, from K-12 to graduate to informal education.

DLESE enables educators and learners to locate and use effective online educational tools, applications, information and data. It also provides an innovative "virtual community center" that offers collaborative networking, news, and opportunities for both teachers and students. DLESE supports resource discovery across a diverse and growing federated network of holdings and collections, including the Alexandria Digital Library Earth Prototype, NASA education collections, multiple peer-reviewed collections, and community-created resources that have been contributed, cataloged, and indexed as part of the overall collections.

As a digital library, DLESE is unique because of its distributed, participatory community design—its "users-as-contributors" approach—engaging Earth science educators from its inception. Critical components of its governance include: working and interest groups; committees on collections, services, technology, and users; and a steering committee that guides policy development and strategic planning.

www.dlese.org

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Diversity

Equity and Diversity

To ensure the nation of a science-literate citizenry able to make informed and reasoned decisions on economic, social and environmental issues, as well as to preserve its global leadership in science, all students require a good education in Earth and space science before graduating from high school. There are, however, wide disparities today in the quality of available Earth and space science education.

There are many reasons for this inequity. School systems in economically disadvantaged communities may lack the resources to hire skilled Earth and space science teachers. They also may be unable to provide adequate Web access, books, and other tools and resources that broaden and deepen Earth and space science education. Students in minority groups based on race, ethnicity or gender lack role models in the scientific community.

For many minorities, be they ethnic, physically challenged or gender, the community itself does not nurture an awareness that they can aspire to a career in science. Peer pressure, however subtle, negates individual thinking that may assist a minority student from breaking out of the mold. Opportunities for students to participate in hands-on, inquiry-based science activities, including authentic research, can help students envisage themselves as scientists.

Teachers, and not only science teachers, sometimes fail to address various ways of thinking and problem solving that are part of different cultural backgrounds. Many teachers are unaware that there are other cognitive processes that are as successful as the Western model. If teachers were better able to communicate with students in their own form of understanding, there would be many more successful students.

Our vision of the state of Earth and space science education ten years from now may seem optimistic, but with the proposed recommendations in place, both short term and long terms goals can be realistically met if we act now. We foresee fair accessibility to Earth and space science education for all students by the year 2010.

Key components of this vision are:

→ availability of instruction that reflects cultural perspectives related to Earth and space science within the classroom population
→ the presence of qualified and diverse Earth and space science teachers within schools that serve target populations
→ an abundance of visible role models within media and schools
→ adequate infrastructure and resources for Earth and space science education within schools that serve under-represented groups (e.g. laboratory equipment, technology resources, access to field sites)

→ flexible and responsive criteria for institutions to access funds earmarked for equity and diversity projects.

To reach this vision, there are barriers in our educational structures that must be overcome. A major one is the inequitable access among schools to laboratory equipment and technology due to limited funding resources. Some schools fail to provide access for students with physical disabilities. Moreover, quality teachers are not equitably distributed in our school systems. There are social barriers as well. Our under-represented groups in the Earth and space science profession are stretched too thin to be effective as role models to all but a few.

Emotional barriers to achieving our goals include science phobia among certain groups and the tracking of many minority students into lower-achieving classes or curricula. Such barriers occur in the classroom and are known as the "Pygmalion effect"; this produces inequality of education when an instructor's preconceived notions of who is successful in science are made apparent to the students. Barriers exist for the quality Earth and space science teachers as well. Many are not aware of the resources available to them and their students; there exist resources now that are specifically aimed at correcting the inequalities of science education in our diverse society.

Certainly these problems of equity and diversity have been explored in depth in numerous studies and reports, such as the National Science Foundation (NSF) Report on Diversity in Geoscience (1999). There also have been several important initiatives to promote diversity in science education in general and/or Earth and space science in particular, such as the NSF Urban Systemic Initiatives, the American Geophysical Union (AGU) Diversity Session (EOS Transactions 2000), AGI Minority Participation Project and the EPA Watershed Manual and curriculum for native American tribes, and teacher training in overcoming gender issues in the sciences. Our recommendations build on insights gained from these and other research and implementation projects.

Equity and Diversity Recommendations

1. Federal and state funding agencies should support professional development and teacher preparation in equity and diversity issues related to Earth and space science education.

These should include local and regional cultural approaches to science, to the Earth and to problem solving. These efforts should be in concert with initiatives detailed in the Professional Development section of this report.

2. The diversity and quality of K-12 Earth and space science educators should be increased.

Potential Earth and space science teachers from under-represented groups should be identified and retained through "bridge" projects that follow students from high school through baccalaureate degree. Professional societies should establish documentation on the qualifications and diversity of Earth and space science teachers, and set benchmarks for improvement. Education institutions serving under-represented populations should be encouraged to, and assisted in, establishing and maintaining educational programs in the Earth and space science, including teacher certification.

3. A community of Earth and space science educators interested in equity and diversity should be established and maintained.

The diversity working group within the Digital Library for Earth System Education (DLESE) and special sessions on equity and diversity during Earth and space science professional society meetings will establish the nexus of the group. The community should ensure broad membership through robust outreach to all potential stakeholders, such as the National Association of Black Geologists and Geophysicists, National Organization of Black Chemists and Chemical Engineers, Society for Advancement of Chicano and Native American Scientists, and the American Indian Science and Engineering Society.

4. Exemplary materials focusing on place-based (e.g. urban) connections to Earth and space science should be developed and disseminated.

Earth and space science can be wrongly perceived as a field of study more appropriate for students in areas close to natural environments than for urban students. This is certainly not the case, as all regions, especially urban areas, are closely connected to the natural environment. For example, the characteristics of the land under and around cities are critically important for defining and shaping them. Major construction projects in urban areas call for deep understanding of the underlying bedrock. Cities are often located near rivers, and have to struggle with issues of water supply, water quality and waste management. Therefore we recommend development of exemplary, inquiry-based materials that feature the connection of Earth and space science to urban environments. This will help make Earth and space science more relevant, engaging and interesting to students in urban schools who often are from minority and under-represented groups.

5. Research on Earth and space science equity and diversity programs and on differing cultural perspectives in Earth and space science should be compiled and future research needs identified.

This is an immediate need that will inform longer-term efforts. NSF should sponsor a review project in conjunction with the Diversity Initiative in Geoscience Education project. New equity and diversity projects should conduct appropriate project evaluation and disseminate results in order to inform other practitioners.

Diversity in Earth Science

FOSTERING EARTH SCIENCE WITHIN MINORITY POPULATIONS

The American Meteorological Society (AMS) offers innovative educational programs to help schools meet the goals of science education. To promote diversity in Earth science, the organization actively recruits teachers who are members of underrepresented groups, or who teach such students, to participate in two key educational initiatives.

The AMA's Project ATMOSPHERE, which is supported by the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA) and AMS members, fosters the teaching and learning of atmospheric sciences in elementary and secondary schools. For greater reach, the project prepares teachers to train their peers. To this end, the AMA seeks minority teachers to participate at a two-week summer workshop at the National Weather Service Training Center in Kansas, MO. Attendees gain the expertise necessary to serve as resources and trainers of other teachers for classroom studies in atmospheric topics.

The Maury Project: Exploring the Physical Foundations of Oceanography is a comprehensive teacher enhancement program based on oceanographic science. The project disseminates instructional materials to schools and prepares teachers to provide peer training nationwide in the use of these and other resources. The project features a special AMS/NOAA initiative to promote minority participation, encouraging teachers of underrepresented groups to attend two-week, summer workshops at the U.S. Naval Academy in Annapolis, MD. There, they will learn how to become peer trainers so they can show other teachers how to introduce oceanography to their students. Since 1994, the workshop's peer trainers have engaged over 18,000 teachers.

These educational projects illustrate the current efforts by both public and private organizations to encourage interest and literacy in Earth science within underrepresented student populations.

www.ametsoc.org/amsedu/aera

www.ametsoc.org/amsedu/maury

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Informal Education

Informal Education and Outreach

We learn much of what we know outside of formal schooling. This kind of learning is called informal education. Informal learning experiences range from museum visits, watching weather forecasts on television, and reading books and magazines, to Girl and Boy Scout merit badge programs. It is voluntary, occurs outside of courses and work leading to academic diplomas, and is the foundation for lifelong learning. Informal learning has long been recognized as a critical component of successful education.

> "A growing body of behavioral research continues to emphasize the importance of early and continued informal learning – from the earliest parental influences; to the development of naive concepts about nature; to the development of strategies for learning and problem solving; to lifelong patterns of self confidence and intellectual curiosity." (George Tressel, in the preface to: <u>Informal Science Learning: What the Research Says About Television, Science Museums, and Community-Based Projects</u> [Crane et al., 1994])

Some of the most magnificent, awe-inspiring artifacts of Earth and space science are found in museums and national parks involved in informal science education. Where else can you lay your hands on an enormous meteorite, stare at a dinosaur skeleton, peer through a powerful telescope or survey a volcano or glacier? Informal settings are rich in resources and brimming with excitement, commodities all too rare in most classrooms. Earth and space science education has much to gain from enlisting the full-scale cooperation of the informal education community.

The United States has a vibrant informal science education community. Millions of Americans of all ages visit museums, watch educational TV, visit the national parks, watch IMAX movies, and use the World Wide Web for informal, on-demand, self-directed learning. In 1995, the Association of Science-Technology Centers (ASTC) estimated that there were approximately 134 million visits to the 364 ASTC-member museums open to the public. This means that more people visit museums than all live sporting events combined (ASTC Newsletter, 1996). Clearly, museums and science centers are integral to cultivating our country's science literacy.

Informal education supports public understanding of science and provides exceptional opportunities for the encouragement and enrichment of formal education and family learning (including home schooling). Informal science learning is provided by:

→ museums, science centers, planetariums, aquariums, zoos, nature centers, botanical gardens

- parks (national, state, local)
- youth groups (e.g., Scouts, 4H, Boys & Girls clubs, after-school clubs)
- after-school enrichment programs and community learning centers
- amateur astronomy, geology and paleontology groups
- local, state, and national government agencies (e.g., NSF, NASA, USGS, EPA)
- professional societies in education and science (e.g., ASTC, NSTA, AGU, ASP, GSA, NAGT, NESTA, AMS, AAS, to name just a few)
- public libraries
- educational radio/TV/Webcast developers
- publishers of books, games, and science activity kits
- newspapers and magazines
- nonprofit organizations such as Earthwatch, the Audubon Society, the Sierra Club, and the Appalachian Mountain Club.

We see four ways in which informal education can help promote the revolution in Earth and space science education.

Collaborating with formal education. As a cultural institution, science progresses only through the rigors of formal study. However, informal education in science plays a significant supporting role in advancing science. We view informal education both as precursor and extension of formal learning experiences. Informal learning can stimulate curiosity that prepares the learner to learn in a formal setting. Similarly, informal settings allow learners to extend learning initiated in the classroom. We strongly encourage formal and informal educators to work collaboratively to provide a variety of diverse, stimulating, and high-quality education experiences for all citizens around core Earth and space science concepts.

Motivating a love of science. Informal science education has a great capacity to catalyze and maintain interest in science among all youth. It does this by providing a learning environment freed from the constraints of curriculum and educational standards, an environment where learners are truly free to pursue their own interests. At the core of informal science education is the opportunity to explore topics of personal interest through curiosity and self-direction, using authentic first-hand encounters with objects, images, or processes upon which science is based. Informal science engages learners with high-quality scholarship at an accessible level. Many scientists trace the origin of their fascination with science to experiences in informal education that captured their imagination.

Creating a scientifically-informed citizenry. Informal science outlets, especially museums, television, movies, newspapers and magazines have a major role in the creation of a scientifically informed and literate citizenry. Citizens of the 21st century will confront a wave of environmental issues requiring basic understanding of the Earth as a system. These issues will continue to confront adults long after they have left formal schooling. Therefore, informal sources of learning new information are nearly the only way that most citizens will acquire the information crucial for dealing intelligently with these issues. Informal science education providers, therefore, should strive to engage citizens in lifelong learning, thereby providing them with opportunities to learn the science necessary to understand topics important in their daily lives. In order to reach across cultural and economic boundaries informal educators should utilize all the tools of popular and new technological media.

Generating new ideas in learning. If properly organized, informal education can serve as an important laboratory for the prototyping and testing of new pedagogical approaches that may be used subsequently in formal settings. Informal education settings are not constrained by tight curricular frameworks and the need to prepare students for high-stakes testing. As a result, they offer science education researchers invaluable and flexible opportunities to experiment with and evaluate how students learn. The exhibit floors of museums can serve as laboratories where researchers try out and evaluate different strategies and techniques in learning. Researchers can study these strategies to try to understand long-term outcomes that may help improve K-12 Earth and space science education in formal settings.

Informal Education Recommendations

1. Engage relevant professional societies in supporting informal Earth and space science education.

The National Science Teachers Association (NSTA) has recently created an informal education committee that has issued a position statement in support of informal science education and its links to formal education. A dialogue should begin and be maintained between the NSTA and leaders representing the community of informal Earth and space science education.

A parallel dialogue should also be opened with the Association of Science and Technology Centers (ASTC) and other professional societies whose members represent a significant part of the informal science education community. We recommend facilitating science talks and professional development sessions on Earth and space science routinely at the meetings of interested societies. We also recommend working with these societies to develop a statement of support for formal science education.

The American Geophysical Union (AGU) is one of the largest scientific professional societies in the world devoted to Earth and space science. The AGU has been developing a policy statement in support of national science education standards and the effective involvement of scientists. We recommend supporting this effort and working to ensure that both formal and informal education are explicitly acknowledged in this statement and others like it from other professional Earth and space science organizations.

2. Facilitate the effective involvement of Earth and space scientists in informal science education.

Funding agencies like NASA and the National Science Foundation (NSF) increasingly encourage the involvement of research scientists in education. We endorse the formation of support networks, coalitions, and/or advisory bodies that can identify and facilitate appropriate opportunities and relationships between Earth and space science research communities and informal education communities. We also endorse training opportunities for scientists in education and public outreach.

We specifically recommend creating and maintaining a menu of opportunities for Earth and space scientists in informal education. This menu could be used to support prospective participants in NSF programs such as the $50K Supplements to Research Awards for Informal Science Education, CAREER, and GK-12. The GK-12 program should be intentionally broadened to the informal realm so that graduate students are funded to develop partnerships with informal learning institutions that support formal education. The recommended menu would also support scientists in NASA's Earth and Space Science Enterprises who are now required to spend 1-2% of their flight program budgets on education and public outreach.

3. Support providers of informal learning experiences in developing high-quality, well-evaluated exhibits, programs, and community events that support the National Science Education Standards.

Many science centers, museums, community organizations, public TV stations and other informal learning providers have exhibits, programs or events related to an Earth or space science discipline. Very few have helped visitors experience and learn about the systemic connections between these disciplines. We advocate increased emphasis on supporting exhibits, programs, and events that: A), make interconnections between Earth system disciplines; B), take full advantage of the connections between Earth and space science; and C), demonstrate science as inquiry. We strongly recommend that inquiry be routinely built into informal education media such as exhibits, open houses, educational TV and radio programs, and so on. Moreover, we recommend increased support for summative evaluation and research on the effectiveness of Earth and space science informal education programs in affecting visitor attitudes, behavior and learning in science.

4. Support exemplary teacher professional development at informal learning institutions and assess the impact on teacher classrooms.

Interactive exhibits, Web-based virtual exhibits, discovery labs, open houses, planetarium and IMAX shows can be used to enhance teacher training and linked to instructional materials identified as exemplary by the formal education community.

We also recommend facilitating dialogue between informal education institutions and schools of education to better prepare pre-service teachers to make use of informal learning opportunities to enrich classroom learning.

5. Assist science centers, museums, and other interested organizations in providing opportunities for students, teachers and families to participate in Earth and space science research, student science competitions and science fairs.

K-12 students and teachers are increasingly engaged in authentic scientific research. Museums and science centers are often well suited to facilitate or inform such involvement. In addition, these institutions are often called upon for ideas related to student competitions or science fairs. We advocate the development and maintenance of a bank of ideas, disseminated by online databases such as the Digital Library for Earth System Education (DLESE), for student involvement in scientific projects related to Earth systems and space science.

6. Establish mechanisms to disseminate timely, accurate scientific information in response to events that attract widespread public interest and attention.

The public is fascinated by news of natural hazards and disasters, by new discoveries in fields with popular appeal such as astronomy and paleontology, by Hollywood movies like "Twister," "Deep Impact," and "Jurassic Park," and by awareness-raising such as Earth Science Week. This widespread attention creates opportunities for learning. We advocate taking advantage of these opportunities by providing access to engaging, scientifically accurate information on the Earth system and space science topics relevant to these events. Information might be disseminated via newspapers and magazines, news media and movie Websites, and in museum exhibits.

To ensure scientific news and information is widely available, we also advocate exploiting technologies that reach underserved audiences and provide new accessibility for those with special needs. One idea for the future is to tie audible Earth and space science data and information to car-based GPS and GIS systems.

7. Create a Web-based clearinghouse for evaluation studies of informal Earth and space science programs and exhibits .

Evaluations associated with science center exhibits very often go unpublished, yet are critical for long-term progress. A Web-based clearinghouse housed at DLESE and coordinated with the Eisenhower National Clearinghouse should be established for evaluation reports and descriptions of "best-practices" related to informal Earth and space science education.

8. Support national and local youth activities with Earth and space science content, such as organization achievement programs (e.g., Scout badges), after-school enrichment programs, amateur groups, science fairs and other events.

High-level leadership should work with leaders of informal education and youth organizations to ensure quality sciences content of national and regional initiatives while working locally with individual groups. One example would be to help the leadership of youth organizations (e.g., Scouts, 4H, Boys & Girls Clubs) to design and support training for achievement awards (e.g., Scout badges) related to Earth and space science content. Opportunities should be sought to disseminate successful local initiatives nationally.

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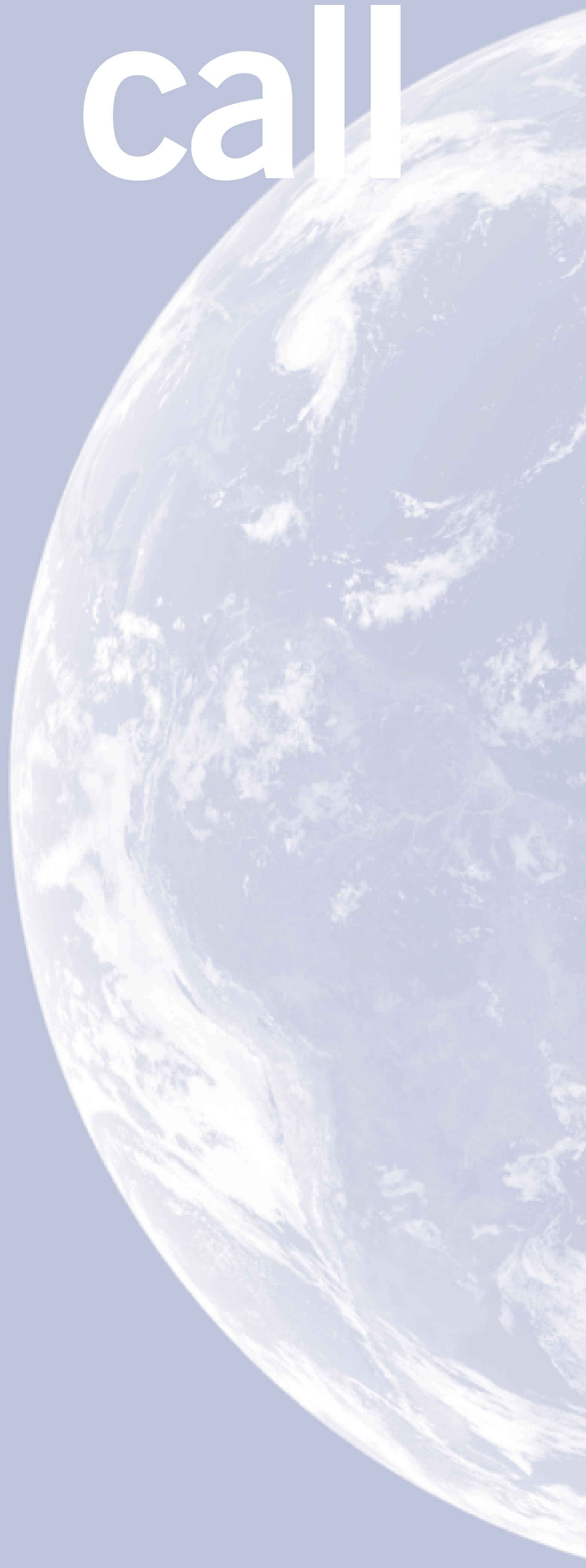

to action

Recommendations

Summary of Recommendations

For the Revolution in Earth and space science education to be successful, a number of specific and coordinated actions must be taken to move from where we are now to our vision of Earth and space science education in the year 2010. The following is a summary of the major actions and changes recommended by the workshop participants as well as a short rationale for each recommendation.

State-Based Alliances:

Establish State-based Alliances to promote Earth and space science education reform. Alliance partners should include educators, scientists, policy makers, businesses, two and four year colleges, museums, technology centers, and others concerned about improving the caliber and scope of Earth and space science education.

Rationale: States are the locus for change in our nation's schools. State departments of education define curriculum frameworks, establish testing policies, support professional development, and in some cases, approve textbooks and materials for adoption. State alliances should work closely with policy makers, district administrators, educators and parents to promote the reforms outlined in this report.

Annual Snapshot:

Develop and conduct an Annual Snapshot of Earth and Space Science Education to gauge progress toward meeting the goals outlined in this report. To measure improvements in Earth and space science education, we need to collect annual data on the current status of Earth and space science education in each state, on student performance, on teacher professional development, and on curriculum reform, and we must monitor these changes over time.

Rationale: The American Geological Institute recently published the "National Status Report on K-12 Earth Science Education." This report provides baseline data on the numbers of students taking Earth and space science at the middle- and high-school level, on the background of teachers teaching Earth and space science, and on high-school graduation requirements. However, additional data are needed on an annual basis to examine the progress of reform efforts and to look at changes in student achievement over time.

Professional Development Academies:

Create national and state professional development academies in Earth and space science. These academies should offer both summer institutes and school-year offerings (online). They should model best practices in teaching, learning, and assessment and encourage K-12 educators to be lifelong learners.

Rationale: Teachers should have an array of high-quality professional development opportunities, helping them to understand Earth as a system, use new technologies, and place a greater emphasis on investigations, in which students pursue answers through inquiry and exploration rather than simply reading text.

Curriculum Reform:

Develop a set of core learning goals for Earth and space science education in grades K-4, 5-8 and 9-12 based on the National Science Education Standards, State Science Education Standards and the Benchmarks for Science Literacy. These learning goals should be more specific than National or State standards, but less proscriptive than a district or classroom curriculum.

Rationale: All students should experience Earth and space science as processes of inquiry, exploration and discovery; they should learn about Earth as a system of interconnected components and processes. Field experiences, the Web and other interactive visualization technologies should be an integral part of the curriculum.

Earth and Space Science as a Lab Course:

Expand the scope of participation in Earth and space science education. Earth and space science education should be taught at all grade levels. In high school it should be part of the standard science curriculum, on par with biology, chemistry, and physics. Development of state-based alliances involving state policy makers, district administrators, educators, business leaders and parents is one method to achieve this goal, as are collaborations with biology, chemistry and physics educators.

Rationale: Currently, many state policies and higher education admissions practices hinder the teaching of Earth and space science to all students. For example, many states require only two years of high-school science to graduate and consequently many students never take Earth and space science. Likewise, many colleges do not currently accept high-school Earth and space science courses as a laboratory science needed for admission, again limiting the number of students in these courses.

Exemplary Student Assessments:

Develop a national database of high-quality, grade-level appropriate Earth and space science assessments. Work with policy makers and state education offices and K-12 educators to ensure that these assessments are aligned with state and district curriculum goals and become a regular part of annual state assessments.

Rationale: Throughout K-12 education there is a strong and growing interest in assessing student learning. Current national and state assessments typically focus on measurements of student factual knowledge. Additional performance and project-based assessments are needed to assess higher order thinking and problem-solving skills, but few such assessments currently exist in the Earth and space sciences. Students should have the opportunity to demonstrate their understanding of scientific principles in a variety of ways and teachers should receive training on how to integrate different types of assessment into the curriculum.

Equity and Diversity:

Enhance access to high-quality Earth and space science resources, mentoring, research experiences and professional development opportunities for students and teachers in high-needs schools. Collaborate with and support existing programs and organizations (e.g. MESA, Upward Bound, SACNAS, AISES, NABGG, Centers for Learning and Teaching, Urban and Rural Systemic Reform Initiatives) and promote the use of the Digital Library for Earth System Education (DLESE) to disseminate resources and create online communities of learners.

Rationale: Students and teachers in high-needs schools often lack the resources, facilities and training found in more affluent schools. All students should have the opportunity to do inquiry-based investigations of Earth and spaces whether they live in urban, rural or suburban areas. In addition, both college-bound and non college-bound students should be encouraged to take courses in Earth and space science. New curricula should include cultural and place-based perspectives and teacher training opportunities should include working with diverse populations.

Informal Education:

Create new opportunities for students and parents to learn about Earth and space science in informal settings. This can be done by strengthening current partnerships and forming new collaborations with the Association of Science and Technology Centers (ASTC), state and national parks, and youth and community organizations. Scientists should be encouraged to collaborate with informal education providers and receive training on working with children and parents in diverse educational settings.

Rationale: We learn much of what we know outside of formal schooling. Informal education is the foundation for lifelong learning and rather than being required, it is voluntary. All students and parents, regardless of location, culture or socioeconomic status should have access to rich and diverse informal learning opportunities focused on the world around them. Strong partnerships between formal and informal educators can ensure that these are high-quality and fun learning experiences.

Research:

Develop a strong research program in Earth and space science education. As we work to reform Earth and space science education, there is an urgent need to understand how students of all types and abilities learn about Earth and space, how to assess student learning, and how to develop curricula that meet the needs of diverse learners. Collaborations with science education researchers in other disciplines can provide a good foundation for developing a research program in Earth and space science education.

Rationale: Research on teaching and learning in Earth and space science education provides the basis for the development of new, more effective curricula and teaching strategies, the appropriate use of new technologies in classroom and field settings, the professional development of teachers, and the creation of high-quality assessments. Currently, only limited research has been done on Earth and space science education.

State Alliances

Overarching Recommendation: State-Based Alliances

In many ways, the states are the most vital locus for change in our nation's schools. State departments of education define curriculum frameworks, establish testing policies, support professional development and, in some cases, approve textbooks and materials for adoption. Hence, we recommend focusing a major effort on state-based reform.

We recommend establishing state-based alliances for Earth and space science education reform. They would include experts in Earth and space science, education and school reform along with key people in positions to influence state policy. The alliances would work towards the broad goals outlined in this report, adapting them for each state's needs, circumstances and opportunities. The alliances will serve as catalysts for change.

This approach builds on similar models of state-based reform used in other fields. For example, for several years the National Geography Alliance has supported reform in geography education based on the National Geography Education Standards. Funded primarily by and coordinated through the National Geographic Society, the project now has Alliance teams in all 50 states and has been a major force for geography education reform.

The experiences of state-based reform efforts demonstrate the importance of building local (i.e. state) ownership and support, as well as direct engagement with the implementation and reform pertaining to each state. This is best done by key experts and people of influence and power in each state.

There also is a need for national leadership and coordination of these efforts. The National Geography Alliance, for example, serves as a stimulus for state efforts, providing resource materials, suggesting strategies and providing expert help as needed or requested. It also provides a forum for sharing ideas and experiences among the state alliances.

Sample Goals

The educational goals of state alliances need to be defined locally for each state. The following are a few key goals that reflect the recommendations of this report.

- All students should have strong learning experiences in Earth and space science education at elementary, middle- and high-school levels
- Students should experience Earth and space science education as a process of inquiry, exploration and discovery.

- Earth as a system should be a dominant paradigm and organizing principle, especially at middle and high school levels.
- Students should regularly use visualization technology and the Internet to better understand core concepts and to support inquiry-based learning.
- Special efforts should support increased involvement of minority, disadvantaged and under-represented students in Earth and space science education.
- A broad array of professional development experiences should help teachers develop skills to implement these reforms.
- Assessment of student learning should be rigorous and directly aligned with the student learning goals listed above.

Sample Membership in Alliances

Each alliance should have a balance of membership including:

- teachers
- administrators
- state department of education
- scientists
- businesses
- colleges and universities (two and four year)
- parents
- professional scientific and educational societies
- museums, planetaria, and other venues for informal education
- and government agencies such as NASA, the United States Geological Survey (USGS), etc.

In all cases, the emphasis is on people involved (better yet, passionate about) Earth and space science education. For example, teacher representatives might be leaders in the state's Earth and space science teacher association. Business representatives might be from the aerospace industry, agriculture or land resource management. Scientists might come from area universities or from science research institutions. Government agencies such as NASA and USGS have strong interests in education and public outreach, and their participation can support reform with a wealth of resource materials.

The alliance might include representatives from other fields of science education, like physics, biology or chemistry or even allied fields such as math and geography.

Sample Domains of Reform

We recommend that each state's alliance should make progress in the following domains.

Coalition Building – The alliance should engage the larger communities in Earth and space science education reform, such as universities, museums, businesses and government agencies. The broader the support, the more likely the change.

Curriculum Reform – The state framework for Earth and space science education should be reviewed to ensure that it clearly defines learning goals at the elementary, middle- and high-school levels. We recommend an increased focus on inquiry-based learning, Earth as a system and use of visualization technologies. These goals are in line with the National Science Education Standards.

Assessment Reform – With the increased emphasis on annual high-stakes testing, assessment tools must mirror the learning goals. There is often a mismatch between curriculum goals emphasizing inquiry-based learning and standardized tests that focus only on memorized facts.

Professional Development – Teacher preparation and professional development are vital for reform. A state's alliance might find ways to infuse Earth and space science education into existing professional development initiatives.

Expanded Use of Technology – States might promote Earth and space science as a cutting-edge exemplar, demonstrating the power of the Internet and visualization technology to support student learning.

Recommended Materials – All states should include the new elements of Earth and space science education (such as Earth as a system and visualization technologies) as essential criteria.

Initiatives for Under-represented Populations – Special initiatives can support increased participation of minority, disadvantaged, female and other under-represented populations. For example, a state might develop learning activities that show the connections between Earth and space science and local urban environments.

Parent Involvement – Earth and space science offers wonderful opportunities to engage parents in learning and exploration. A state's alliance might develop vignettes demonstrating how parents can help their children observe and explore their environment, connecting to central themes in Earth and space science.

Informal Science Education – Museums, aquaria, planetaria and other centers for out-of-school learning provide a wealth of opportunities for children and adults to experience Earth and space science. A state alliance might align a museum's exhibits with Earth and space science education reform, such as featuring visualization technology akin to what students will experience in schools.

Funding – Each state's alliance can help identify, tap into and, in some cases, increase funding for Earth and space science education. For example, alliance members might encourage local foundations to support reform efforts in Earth and space science education, such as new technologies for schools or developing urban-focused materials.

Grand Challenge

To provide a clear and galvanizing focus, each state's alliance should also take on a "grand challenge" that integrates these domains. Each state, for example, might develop an education guide to local and regional water issues. Colorado might focus on the Rocky Mountains, California might deal with coasts, Florida with reefs, Nebraska with groundwater and Arizona with deserts. Each state would identify existing issues and resources, and then develop sample case studies and inquiry-based investigations for water in the Earth system. Such materials could exemplify new approaches to Earth and space science education and help schools implement reform. States can share their resources with each other, creating a wealth of exemplary topics and inquiry-based learning activities—all working towards the larger goal of Earth and space science education reform.

Annual Snapshot

Overarching Recommendation: Annual Snapshot

Successful change is both driven and monitored by structured assessments of progress. Therefore, we propose an Annual Snapshot of K-12 Earth and Space Science Education. These Annual Snapshots will provide implementers, policy-makers and the nation at large with a status report on the nature and extent of Earth and space science education. The Annual Snapshot will provide a sense of progress as well as identify persistent or emerging needs to be met in order to achieve the reforms detailed in this report.

The Annual Snapshot should take an integrated and comprehensive view, with comparisons from one year to the next, and with recommendations correlated with the goals of the "revolution in Earth and space science." The Annual Snapshot should be implemented by an independent organization or group of organizations with experience in Earth and space science education and evaluation, ideally with funding from the National Science Foundation, NASA, the U.S. Department of Education or other government agencies.

The detailed structure and methods for the report will need to be defined by the evaluators, with general support from the Earth and space science education community. While these details should be developed and embodied in a full evaluation plan, we recommend that the annual assessment include the following components:

1. State-by-State Status Report – This component will provide a summary of each state's current policies, procedures and extent of student participation in Earth and space science. This will include the extent of Earth and space science in state curriculum frameworks and student assessments, whether or not Earth and space science is mandated, and, to the extent this information is available, the numbers of students in Earth and space science classes. An initial version of this component has already been launched through the American Geological Institute's "Report on the Status of K-12 Earth Science Education" released in November, 2001.

2. Student Performance – This component will provide a summary of student performance in Earth and space science. For example, this could use an analysis of Earth and space science related items on existing instruments, such as the National Assessment of Educational Progress (NAEP) and state-based annual assessments. As new measures emerge, they should be included—especially those that feature the priorities recommended here like a greater emphasis on Earth as a system, inquiry-based learning and the use of visualization technology.

3. Teacher Professional Development – This component will provide statistics on the status of teacher professional development in Earth and space science. For example, it will be very useful to have data on the level of training in Earth and space science content and methods for teachers of Earth and space science, especially at the high-school level. This will also include data on the extent of Earth and space science content and methods in teacher preparation programs.

4. Curriculum and Materials Development – This component will look at the nature of Earth and space science curriculum requirements at the state level, especially at the degree to which such curricula reflect the priorities articulated in this report. This component will also look at the nature of the materials most commonly used in classrooms at elementary, middle- and high-school levels—again with an eye to the reforms proposed here.

5. Diversity – This component will provide data on the diversity of students and teachers in Earth and space science education, as well as describe current examples of diversity initiatives. For example, this component might sample urban school districts to monitor the level of participation of minority or socio-economically disadvantaged students in Earth and space education.

6. Vignettes of Reform – The Annual Snapshot will conclude with a look at cutting-edge examples of reform in Earth and space science programs and practice, such as those described throughout this report. While use of such programs may not yet be widespread, they serve as models for leadership. This will also include a comprehensive (or at least illustrative) list of innovative Earth and space science programs funded by NSF, NASA, USDE and other federal agencies. It will also include contact information for those wanting to adopt these programs or get more information.

We expect that other components of the Annual Snapshot will be worked out in the full evaluation plan. The essential point is to have a solid, integrated and comprehensive view of the status of K-12 Earth and space science education, with year-by-year comparisons and analyses, as a means to monitor and support the goals of the revolution in Earth and space science education.

appendix

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Brief History of Earth Science Education

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Introduction

While elements of geology, astronomy, physical geography, and environmental sciences were taught in schools at the turn of the 20th century, today's Earth science courses are a recent addition to K–12 education. An examination of the development of Earth science education provides an understanding of how science courses are introduced, evolve over a period of time, and are replaced by other courses. To fully understand how Earth science fits into the curriculum, it is helpful to study the development of science education from when science was introduced into schools in colonial times through the National Education Association's (NEA) Committee of Ten recommendations in 1894.

The Development of Science Education in America

Early settlers to the North American continent came from a wide variety of countries and brought with them the education systems of their cultures. Training in the classics and religion were important subjects of the day. Earliest learning took place in the home but this gave way to the "petty or dame school" in which women with basic skills in reading and writing would take students into their home. A second type of school, the writing school, taught "writing, reckoning, and…merchants accounting." The writing school gradually merged with the dame school to form the school of 3-Rs, "reading, [w]riting, and [a]rithmatic." (Cubberley, 1948).

Thomas Jefferson, advocating education, stated: "If a nation expects to be ignorant and free, in a state of civilization, it expects what never was and never will be." In 1779, Jefferson introduced a bill for public education in Virginia. He proposed a tiered school in which students would have "three years gratis, and as much longer as they please paying for it." The first three years would be devoted to "reading, writing, and arithmetic." Under Jefferson's plan, "twenty of the best geniuses will be raked from the rubbish annually and instructed at public expense." After six years of instruction, ten of the twenty would be chosen to continue on to William and Mary College (Raubinger et al, 1969).

Breaking with the European tradition, Benjamin Franklin railed against the status of colonial education and in 1749 published "Proposals Relating to the Education of Youth in Pennsylvania." Franklin's treatise called for the establishment of schools to teach "useful" subjects such as English, geography, history, natural history, health, astronomy and agronomy. Franklin established an institution of higher learning he called an "academy for the education of youth," which ultimately became the University of Pennsylvania. In 1778 the Phillips brothers, acting on Franklin's ideas, founded academies in Andover, Massachusetts and Exeter, Massachusetts. These academies and others accepted both male and female students who could pay for their education. The academy plan rapidly expanded, offering a wide range of subject matter.

By 1850 academies were the dominant form of education with over 6000 in place (Raubinger et al, 1969). In following Franklin's admonition to teach useful subjects, the academies offered science classes in addition to other subjects and became the first important nineteenth century institutions to promote the study of science. Science teaching at academies, however, was not always of high quality and often consisted of courses as short as six weeks, with inadequately prepared teachers and poor or non-existent textbooks. Because the academies charged tuition, a large block of the population could not afford schooling (DeBoer, 1991 and Sizer, 1964). At the close of the civil war, academies continued to grow and at the end of the last century, with an education system in place, educators turned their work to creating a sequence of courses that would best serve future citizens.

At the close of the 19th century the National Education Association's (NEA) Committee of Ten met to establish a norm for the types of courses for schools to teach. Not surprising, as the committees and subject conferences were composed predominately of university and college faculty, NEA's recommendations were based on the assumption that students were college bound. To arrive at a final report the committee reviewed the recommendations of nine subject conferences. Two major recommendations of interest here are:

→ A joint science subject meeting resolved that science should occupy at least 25 percent of the overall syllabus.

→ Based on the science conferences recommendations, the Committee of Ten recommended that physical geography be taught at the ninth grade, biology in the tenth, chemistry in the eleventh, and physics in the twelfth (NEA, 1894.)

What is Earth Science?

In the late 1950s Earth science was introduced as a special class in New York and Pennsylvania. These were the first states to adopt Earth science as part of a state-mandated curriculum. In a series of articles published in the early 1960s, more than a dozen authors stated their opinions of Earth science course content. These writers listed disciplines they thought should be included in Earth science or listed disciplines they perceived to be part of the definition of Earth science education. If these authors' recommendations are combined into common themes, their ex post facto content recommendations are geoscience 28 percent, meteorology 24 percent, oceanography 24 percent, and space science 25 percent. By 1964 Earth science was offered in 44 states to over 190,000 students nationwide, displacing physical geography and general science at the ninth grade. Hailed by some authors as a model of inquiry-driven curriculum, the Earth Science Curriculum Project (ESCP) was released in 1967, setting the standard for Earth science education and promoting further enrollment. Unfortunately this trend began to wane during the 1980s.

The American Association for the Advancement of Science's (AAAS) Benchmarks for Science Literacy (AAAS, 1993) and Science for All Americans (AAAS, 1989) set content guidelines for all disciplines and included Earth and space science as a core science. Combined with the introduction of the National Science Education Standards, (NRC, 1996), with a specific call for the inclusion of the Earth and space sciences across the K–12 curriculum, there has been a resurgence in Earth science offerings nationally. However several states—notably California, Texas, and Massachusetts—recently attempted to drop Earth science from the curriculum. In Massachusetts a concerted effort by teachers, parents, and geoscience professionals reversed this decision. California and Texas are still in limbo as of this writing.

Conclusions

What is happening in Earth science classrooms? Anecdotal discussions with teachers reveal a wide variety of opinions as to what should be included. It has often been noted that classroom content closely follows textbook content (Shymansky et al, 1994 and Zahorik; 1991). With this in mind, ten textbooks surveyed for this study contained a total of 225 chapters. Six chapters were introductory in nature and omitted. The 219 remaining chapters were coded to match the four Earth science themes resulting in 120 chapters devoted to geology, 34 to meteorology, 23 to oceanography, and 42 to space sciences. If teachers teach from their textbooks then geology occupies 55 percent of teaching and the other three themes—meteorology, oceanography, and space sciences—are taught during the remaining 45 percent of the time.

The methods used to teach Earth science are open and changing. With the exponential growth of the Internet and the availability of supplemental materials, teachers are able to reach beyond the standard textbook. Visualization activities using satellite images, GIS, and other remote-sensing databases expand the teacher's capabilities to have students involved in research projects beyond the classroom to look at the Earth as a complex system. Both the NRC and AAAS works include guidelines for teaching methods. Both the NRC and AAAs works include guidelines for teaching methods and, along with many educators, call for an inquiry, guided learning approach to teaching. The National Conference on the Revolution in Earth and Space Science Education in Snowmass, CO, was held specifically to address the challenges of teaching standards-based Earth and space science in the 21st Century. As a follow-up the Coalition for Earth Science Education (CESE) focused the attention of its 2002 meeting on enacting and promulgating recommendations from the Snowmass conference.

This history of the development of science education in the United States from colonial times to present has shown what we teach and how we teach will continue to evolve. As E.J. Houston, member of the NEA Committee of Ten, offered: "A tendency unfortunately exists in educational circles to decry all that is old, and to laud and magnify all that is new. Such is the fruit of specialism, not of broad culture" (NEA, 1894). As Earth scientists who are taught to follow a multiple working hypothesis, we must remain open to suggestions in order to find an answer to these questions.

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Building on the Work of Others

In this report, we call for a revolution in Earth and space science education. It is important, however, to bear in mind that we are building upon the efforts of others. The following statement was endorsed by several science and education organizations in 1987.

The Importance of Earth and space science Education

K-12 Earth and space science plays a unique and essential role in today's rapidly changing world. It is an integrated study of the Earth's history, composition and structure, its atmosphere and oceans, and its environment in space. A knowledge of Earth and space science is important because most human activities are related to interaction with the planet Earth.

Basic knowledge about the Earth, then, is the key to development of an informed citizenry. The reasons for teaching Earth and space science are numerous: it offers experience in a diverse range of interrelated scientific disciplines; it is closely related to the students' natural surroundings; and offers students subject matter which has direct application to their lives and the world around them. They need only step outdoors to observe and find relevance in concepts learned in the Earth and space science classroom. Because it offers many opportunities to collect data, hypothesize, experiment, and draw conclusions, both within school and outside environments, Earth and space science is a laboratory and activity oriented course. Earth and space science integrates many principles of both physical and life sciences. It incorporates and presents concepts often not emphasized in other parts of the science curriculum, such as geologic time and the vastness of space.

The teaching of Earth and space science allows all students to have a better science background with pertinent information about their surroundings. Daily, society is faced with environmental and economic concerns such as acid rain, water supply, the greenhouse effect, and waste disposal. Civilization is absolutely dependent upon utilization of Earth's energy, mineral, and human resources. Awareness of natural phenomena such as floods, tornadoes, hurricanes, volcanoes, and earthquakes also requires a knowledge of Earth and space science.

Students who study Earth and space science are better prepared to discuss issues and make informed, responsible decisions. The interdisciplinary curriculum of Earth and space science develops and builds on skills learned in earlier grades and closely relates to the students' everyday experiences. It develops attitudes and problem-solving skills that will be useful throughout life. If tomorrow's adults are to make wise decisions about Earth and environmental issues, it is vital that today's students be given the opportunity to study Earth and space science at all levels as an integral part of their education as well as an invaluable part of their high school experience.

Approved by National Earth Science Teachers Association – March 28, 1987

Endorsed by National Science Teachers Association – July 29, 1987

Endorsed by Council for Elementary Science International – October 17, 1987

Endorsed by National Association of Geology Teachers – October 27, 1987

Endorsed by American Geological Institute – October 28, 1987

Endorsed by American Geophysical Union – May 17, 1988

1987

2001

American Geophysical Union Calls For Earth Science Education

For over 75 years, the venerable American Geophysical Union (agu.org/homepage.html) has supported and publicized the research by geophysicists into our planet and its environment. This community of over 38,000 scientists from 117 countries recognizes the critical importance of K-12 Earth and space science education and in December 2001, officially adopted the following policy statement:

Importance of the Earth and Space Sciences in Primary and Secondary Education: An Endorsement of the AAAS Benchmarks and NRC Standards

Citizens require a solid understanding of the Earth and space sciences to address responsibly many of the issues confronting society, such as climate change, natural hazards, and resource availability. In the U.S., the only opportunity for most people to learn science in a formal setting occurs in grades K-12 (kindergarten through high school). In addition, a positive K-12 science experience may inspire young people to pursue the further study of science. As a community dedicated to advancing the understanding of Earth and space, the American Geophysical Union (AGU) is committed to effective science education in the primary and secondary grades.

The National Research Council (NRC) and the American Association for the Advancement of Science (AAAS) have independently addressed ways to improve the quality of K-12 science education. Their recommendations are published in National Science Education Standards (NRC, 1995) and Benchmarks for Science Literacy (AAAS, 1994). These documents outline specific concepts that students should know, understand, and be able to apply in order to be scientifically literate. They also suggest effective methods for teaching science. Both documents include the Earth and space sciences, along with the physical and life sciences, as essential elements in education at all grade levels.

The American Geophysical Union endorses the recommendations for teaching Earth and space sciences contained in Benchmarks for Science Literacy and National Science Education Standards. AGU urges local and state education agencies to implement these recommendations in the primary and secondary grades.

Declaration of Importance National Conference on the Revolution in Earth and Space Science Education

2001

At the National Conference on the Revolution in Earth and Space Science Education, participants enacted and signed the following statement as an endorsement of the importance of Earth and space science education and as a call to action.

"As our nation deliberates on education policy and funding, we, as leading science educators and scientists, call for legislators, decision makers, and stakeholders to implement all measures that support science education in general and earth and space science in particular.

Fueled by new technologies over the last 40 years, advances in Earth and space science are revolutionizing our understanding of Earth's systems and processes. This growing understanding is increasingly needed to inform political and economic decisions of local, national and global impact.

For this reason, a science-literate citizenry is vital to the nation's well-being and security and will insure our nation's continued leadership in science and technology in the 21st century. To empower the public to make sound and reasoned choices, earth and space science must be taught throughout the United States in K-12 classrooms and be accessible to all students."