Revolutionizing Earth System Science Education for the 21st Century

Report and Recommendations from a 50-State Analysis of Earth Science Education Standards

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For copies of this report in PDF format, a downloadable database of the standards analyzed in this study, and annotated PDF of the standards from each state, visit the Web sites: www.terc.org or www.oesd.noaa.gov

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Executive Summary

Call to Action

Understanding Earth's interconnected systems is crucial to the future of our nation and the world. Yet our nation's schools have a mixed record of effective Earth science education. While Earth science concepts are taught throughout K-12 education, these learning experiences are often considered of less rigor and substance than other domains of science.

In recognition of this disconnect between pressing needs and current practice, many states are reshaping their Earth science standards, curricula, and high-school science graduation requirements. These states are revolutionizing their approaches to Earth science education by moving towards a "21st century" view of Earth science, with an increased focus on Earth as a system, use of new visualization technologies that reveal Earth's processes in powerful ways, recognition of Earth science as a cutting-edge domain of vital importance for our future, and responsiveness to the national call for workforce development.

Though significant improvement is occurring in several states, the process of revolutionizing Earth science education across the nation is a work in progress. Existing science education standards across the nation incorporate some aspects of these vital concepts, but they do not fully embrace them.

Knowing which revolutionary Earth system science concepts areas are well covered, as well as those that are not, serves to establish a baseline of understanding that, in turn, can inform the development of a blueprint for revising and strengthening Earth system science standards over the next decade. This study establishes such a baseline.

This study also provides the National Oceanic and Atmospheric Administration (NOAA) with detailed information that will support implementation of its education plan to "establish an environmental literacy program to educate present and future generations about the changing Earth and its processes, to inspire our nation's youth to pursue scientific careers, and to improve the public's understanding and appreciation of NOAA's missions" (Department of Commerce, 2004). Specifically, this study provides NOAA with detailed information regarding the extent to which state K-12 standards address NOAA's domains of strategic interest—particularly ocean, atmosphere, and environmental literacy.

Review Criteria

This study examined how well Earth science standards across the country incorporate seven forward-looking perspectives and approaches to K-12 Earth science education. These perspectives include four cutting edge "revolutionary" Earth science education approaches: Earth considered as a dynamic

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interactive system; Earth examined through the perspective of space-age tools; use of 21st century technologies in Earth science research; and application of inquiry-based approaches to teaching and learning about Earth science. Three criteria specifically tied to NOAA's principal areas of strategic responsibility complete the set of seven perspectives examined. These three NOAA-specific domains are: ocean literacy principles and concepts; atmosphere, weather, and climate content; and environmental literacy principals and applications.

This study analyzed K-12 Earth science standards and frameworks of all fifty states, plus the District of Columbia, to determine how well each state's standards address these seven Earth science content and pedagogical criteria.

Findings

Unfortunately, this study shows that Earth system science education in the U.S. is in need of significant improvement. As a whole, we found that there is great variation in the degree to which states currently incorporate modern Earth science perspectives into their science standards.

Approaches and perspectives articulated by the National Science Education Standards (e.g. inquiry-based learning and system-based perspectives) were found to be commonly included within state standards. For example, we found that inquiry-based learning approaches are incorporated into every state's standards to some degree. While system-based thinking is a part of every state's standards, only thirty-five of the states directly presented the perspective of Earth as a set of interacting systems. Perspectives derived from traditionally covered subject areas (e.g. atmosphere, weather, and climate) were commonly present, but satisfactorily so in only two-thirds of the states.

Recently emerging Earth science education approaches and perspectives, including 21st century technology and the space-age research perspective, were each found to be directly articulated in only a minority of the states' standards (18 and 11 states respectively). The ocean literacy principles and concepts, formulated in 2005, were not found to be commonly present in most state's standards. The best seven states included only sixteen to twenty of the thirty-five different ocean literacy concepts analyzed. Twenty states directly articulated a fairly complete suite of environmental literacy perspectives while seventeen states inadequately addressed environmental literacy concepts.

These findings point to a disconnect between the pressing need for an Earth system literate society and the current K-12 education system that is responsible for developing this capacity.

Executive Summary

This study provides a detailed national picture, for this point in time, of the degree to which modern Earth science perspectives are incorporated in standards. As such, these findings can be used as a benchmark to measure changes in standards over time. More importantly, this analysis can be used to help establish strategic steps for revolutionizing Earth systems science education.

Recommendations

Knowing the current, less-than-rosy status of Earth system science education across the U.S. highlights a pressing need for systematic reform. This report is therefore a call to action. State K-12 science education standards must improve their coverage of crucial Earth system science concepts and approaches to teaching. We propose the following set of recommendations as a starting point in the process of revolutionizing K-12 Earth science education.

- ❖ The concepts and approaches comprising the seven different review criteria should be viewed as an interrelated suite of perspectives, all supporting the core principles of quality Earth systems science education. Thus, any efforts to enhance inclusion of these perspectives into more state standards should focus not on one particular perspective, but simultaneously on multiple perspectives.
- ❖ The ocean literacy principles and concepts could be enhanced by better incorporating a systems perspective. More overt acknowledgement of the interactions between the ocean and other systems would help educators successfully incorporate ocean literacy concepts into the broader study of Earth sciences. Ocean literacy thus does not have to be viewed by educators as a replacement for other Earth science content, but instead as the conceptual glue that binds together many aspects of Earth science study. Ocean literacy might be better served and more readily incorporated into state standards if ocean concepts were highlighted within the context of systems dynamics and interactions, rather than being a standalone theme in the standards.
- ❖ Develop a comprehensive set of atmosphere, weather, and climate literacy principles and concepts, similar in format to the ocean literacy principles and concepts. Such a synthesis will provide clarity to states regarding the essential understandings and process of atmospheric sciences.
- ❖ Directly participate in state science standards revision processes. Public, academic, as well as state and federal agency input provides valuable perspectives that help the state develop a more thoughtful product. Recently revised state standards that involved participation by the authors

of this report were found to better articulate the modern approaches to Earth science education than the old standards.

- ❖ Ensure that Web-based access to data and analysis tools are usable by the K-12 education community.
- ❖ Participate in the development of quality state and national science assessments. It is vital that these assessments cover Earth system science concepts; otherwise schools have little incentive to teach Earth system science to their students. Likewise, the format of the assessments should match the skill sets, data sets, and research tools deployed by students as they explore Earth systems science in their classroom learning.
- ❖ Demonstrate that modern “revolutionary” Earth science perspectives and approaches to teaching result in deep student learning of science concepts and thinking skills. This is a multi-step process. Step one involves developing and distributing model Earth science curricula that incorporate the revolutionary perspectives examined in this study. Next, the effectiveness of these curricula and approaches needs to be assessed via objective evaluation processes. After refinement, the final curricula must be widely distributed.
- ❖ Establish Earth system science as a science course widely viewed as being equally or more challenging as the classic high-school sciences of biology, chemistry, and physics.
- ❖ Tirelessly persist in promoting the revolution in Earth system science education with the understanding that improvements will occur incrementally.

A Call to Action

50-State Analysis of Earth Science Education Standards

Understanding Earth's interconnected systems is vital to the future of our nation and the world. Ocean and atmospheric interactions effect our daily lives in multiple, significant ways. Long-term changes in ocean and atmospheric processes impact national economies, agricultural production patterns, severe weather events, biodiversity patterns, and human geography. Global warming and its effects on glacial mass balance, sea level, ocean circulation, regional and global weather and climate, and coral bleaching, to name only a few potential impacts, are important global issues that demand immediate attention. Advances in scientific research tools and methods over the past several decades have enabled Earth system scientists to better understand how complex systems function and to create more accurate models with which to predict a range of system changes resulting from natural interactions and human influences. All of these issues point to the pressing need for developing an educated society that is literate and aware of natural Earth system processes and humanity's role in altering these systems. Long-term, sustainable use of this planet will increasingly depend on our ability to understand how it functions.

Our nation's schools have a mixed record of effective Earth science education. While Earth science concepts are taught throughout K-12 education, these learning experiences are often considered of less rigor and substance than other domains of science. In response, many states are reshaping Earth science education, moving towards a "21st century" view of Earth science with an increased focus on Earth as a system, use of new visualization technologies that reveal Earth's processes in powerful ways, recognition of Earth science as a cutting-edge domain of vital importance for our future, and responsiveness to the national call for workforce development. National initiatives, such as the new *Ocean Literacy: Essential Principles and Fundamental Concepts*, help define the direction these changes should take.

Yet revolutionizing Earth science education is still a work in progress. Existing science education standards across the nation incorporate some aspects of these vital concepts, but they do not fully embrace them. Identifying areas that are well covered, as well as those that are not, will help to establish a blueprint for revising and strengthening Earth system science standards over the next decade.

Developing this blueprint for change requires a detailed analysis of where we are now. While several studies have taken a broad view of state science standards, this is the first such study focusing specifically on Earth system science. This study thus establishes a baseline——a comprehensive, fifty state analysis of Earth system science in each state's science education standards.

A Call to Action

We focus especially on the revolutionary new approaches to Earth system science education. Since this project was funded by the National Oceanic and Atmospheric Administration (NOAA), we also give special attention to NOAA's primary domains of ocean, atmosphere and environmental literacy.

This report presents the results and recommendations from this study of K-12 science standards of all fifty states and the District of Columbia. These findings represent a snapshot of current approaches to Earth system science education across the United States. Specifically, it summarizes how well every state addresses each of seven major Earth system science concept areas and approaches to Earth system science teaching—Earth as set of interacting systems; ocean literacy; atmosphere, weather, and climate; environmental literacy; space-age perspectives; 21st century technology; and inquiry-based approaches to teaching Earth science. Findings resulting from a detailed analysis of each state's coverage of thirty-five fundamental ocean literacy concepts are also presented. Also included are findings regarding the acceptance of Earth science as a laboratory course for high school graduation.

This report informs and serves multiple audiences—science education policy makers at the federal, state, and district levels; policy makers working for agencies whose domains of interest include Earth science—e.g., NOAA, NASA, USGS; Earth system research scientists; educational curriculum developers; assessment developers; teacher professional development providers; Earth science teachers; as well as individuals and groups involved in systematic education reform efforts.

Unfortunately, the findings of this study show that Earth system science education in the U.S. is in need of significant improvement. Even though most states at least generally approach Earth as set of interconnected systems, they are less consistent in addressing fundamental ocean literacy, atmospheric literacy, environmental literacy, space-age perspectives, and 21st century technology related concepts. This points to a disparity between the pressing need for an Earth system literate society and the current K-12 education system that is responsible for developing this capacity.

The inadequate state of the nation's Earth system science education highlights the pressing need for systematic reform. Thus, this report is a call to action. State K-12 science education standards must improve their coverage of vital Earth system science concepts and approaches to teaching. In addition to calling for action, we present a blueprint for reforming K-12 Earth science education standards.

Context

K-12 science education within the Unites States is poised at a critical juncture. Pressure for reform is coming from many different sources and perspectives. Federal legislation—particularly No Child Left Behind—calls for intensive assessment of student learning, which by many reports is forcing teachers to “teach to the test.” NCLB mandated all states to define science standards for the 2005-6 school year, and to assess science learning beginning in 2007-2008. Many states have consolidated the content of their science standards and are preparing state-based science assessment in response to these mandates and initiatives.

In the midst of this assessment-focused reform are major studies, such as *Rising Above the Gathering Storm* (Committee on Science, Engineering, and Public Policy, 2006), that cite the major challenges our nation faces in global competitiveness and workforce development in science, math, technology and engineering. These reports call for stronger science education programs to challenge and engage all students, as well as deeper opportunities for bright and motivated students to pursue more advanced studies in high-school science. Another study, *America’s Lab Report* (NRC, 2006), asserts that deep learning of science content and thinking skills is best accomplished through extended investigations that tie experimental labs, observational science, field studies, computer-based data acquisition and analysis, and textbook learning into an integrated laboratory learning experience.

Looking more specifically at Earth science, a 2001 NSF-funded conference of scientists, educators and policy-makers prepared a pivotal report calling for a national revolution in Earth science education, with recommendations for enhancing Earth science education and expanding its reach to more students. *The Revolution in Earth Science Education* report (Barstow and Geary, 2002) has become a driving force in national and state policy reform.

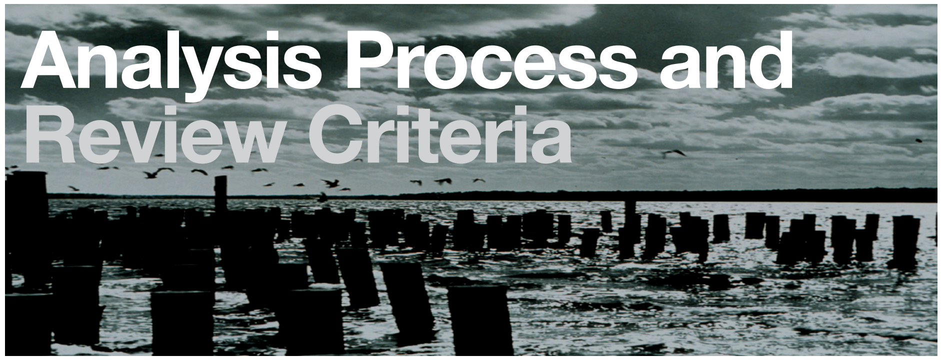
More recently, a broad coalition of ocean scientists, educators, and policy makers developed *Ocean Literacy: The Essential Principles and Fundamental Concepts of Ocean Sciences* (Cava et al., 2005), which clearly outlines what students need to know to be informed, ocean literate citizens. This document has had a remarkably important impact on the field of Earth system science education, providing clear guidance to states as they revise standards and develop assessments.

Opportunities to incorporate the ideas articulated by these key Earth science education reform documents arise as states revise standards and develop assessments. Capitalizing on these opportunities first requires understanding the extent to which these revolutionary approaches and concepts are currently incorporated into state standards. This study is intended to provide this crucial baseline information.

Context

This study also specifically intended to provides NOAA with detailed information that will support implementation of its education plan to “establish an environmental literacy program to educate present and future generations about the changing Earth and its processes, to inspire our nation’s youth to pursue scientific careers, and to improve the public’s understanding and appreciation of NOAA’s missions” (Department of Commerce, 2004). Specifically, this study provides comprehensive data regarding the extent to which state K-12 standards address NOAA’s domains of strategic interest—particularly ocean, atmosphere, and environmental literacy. This knowledge will help inform NOAA’s educational, scientific, and advisory programs.

Analysis Process and Review Criteria



This study analyzed K-12 science standards and frameworks of all fifty states, plus the District of Columbia, to determine how well each state's standards address seven different Earth science content and pedagogical criteria. The focus of this study was on Earth science across the K-12 grade span. Standards for other subject areas—physical science, biology, chemistry, physics—were not reviewed or analyzed.

We reviewed four over-arching criteria – the key elements of "revolutionary" Earth science education:

1. Earth as a dynamic interactive system
2. Space-age perspective
3. 21st century technology
4. Inquiry-based approaches.

We also reviewed three criteria relating specifically to NOAA's strategic domains:

5. Ocean literacy
6. Atmosphere, weather and climate
7. Environmental literacy.

We provide detailed descriptions of each review criterion in the Findings sections.

We used a two-step process.

1. **Annotated PDF files of all standards** - All states provide their standards online. We downloaded the Earth science component of all the state standards, and, if needed, converted them to Portable Document Format (PDF). We then used Adobe Acrobat© as a highlighting and labeling tool to find and mark the statements relevant to our study. All of the statements that dealt with the seven Earth science review criteria were digitally highlighted and assigned labels identifying the review criteria addressed by each specific statement. Statements that addressed more than one review criteria were given multiple category labels. Next, we bookmarked each of the highlighted and categorized statements so that they could later be easily located and reviewed within the context of the entire standards document. We organized these annotated standards and posted them online at www.oesd.noaa.gov and www.terc.edu.

2. **Analysis of standards based on target criteria** - In the second stage, we analyzed all of the standards statements for each state that addressed a particular review criterion. Based upon this comprehensive analysis, we assigned one of three possible overall grades for each review criteria for each state, as detailed in Table 1. In some cases, this involved subjective

Analysis Process and Review Criteria

judgments, but we feel that the three tier ranking provides a reasonable and useful level of analysis. We did not review the factual accuracy of the standards statements.

NOAA also requested a more detailed analysis of the ocean literacy essential principles and fundamental concepts, so we used the same process to review thirty-five[1] specific ocean literacy concepts.

The table below illustrates the grading scale, the indicators for each level, and examples from the state standards.

Table 1: Review Criteria Grading Rubric

Grade	Indicator	Example Standards
Directly (D)	• Statements directly articulate or refer to two or more major components of the specific review criteria. • Direct statements span multiple grade levels. • Major concepts of review criteria progressively developed over the K-12 grade span	1) Describe how organisms on Earth contributed to the dramatic change in oxygen content of Earth's early atmosphere. (Ohio) 2) Describe the use and benefits of land based light telescopes, radio telescopes, spectrophotometers, satellites, manned exploration, probes, and robots to the study of Earth Space Science. (New Hampshire)
Indirectly (I)	• Statements can be interpreted to include one or more components of the specified review criteria, but do not directly mention the major components of the specific review criteria. • Statements span more than one grade level.	1) Describe how Earth's atmospheric composition has changed from the formation of the Earth through current time. (Mississippi) 2) Explore past, present, and future space technology. (Arkansas)
Fails (F)	• Statements addressing the review criteria are absent from standards or so generalized that review criteria cannot be assumed to be addressed by the standards. • Statements found only at one grade level.	

[1]This study examined thirty-five of the forty-five fundamental concepts of ocean literacy. We did not analyze the ten biology fundamental concepts underlying essential principle number five, "The ocean supports a great diversity of life and ecosystems." These ten concepts were not examined because the focus of this study was on Earth science standards rather than biology standards.

Analysis Process and Review Criteria

State standards, at the level of each state and across the nation as a whole, are messy. Very little consistency exists between different states' standards, especially within the Earth and space science subject area domain. A slightly higher degree of inter-state consistency occurs within the realm of inquiry-based approaches to science teaching. While the National Science Education Standards (NRC, 1996) and Project 2061 Benchmarks for Scientific Literacy (AAAS, 1991) significantly influenced the general content of many states' standards, many other factors have also informed each state's standards. Each state has its own development processes, generally involving a wide variety of people with different backgrounds, subject area expertise, teaching experience, special interests, and political agendas. These processes result in widely varying standards. Assessment programs mandated by law (i.e. No Child Left Behind and state mandated high school exit exams) have also significantly affected the contents of state standards. The net result is the observed diversity of standards across the nation.

The untidy nature of standards presented a major challenge for this study—how to objectively and consistently apply the grading criteria to a wide diversity of standards statements? Reviewing diverse standards to determine how well they cover specific concepts or apply specific approaches to Earth system science teaching is admittedly a subjective undertaking.

Consistency in the analysis process was established by having a single reviewer evaluate all of the statements for all states. The subjective nature of this assessment dictated the use of generalized summary grades (direct, indirect, failing), rather than finer grained grading schemes, to rank each review criteria.

While the authors of this study have worked at objectifying this analysis, some may disagree with the grades assigned. We therefore welcome comments, feedback, and clarification from states that believe that we have misinterpreted their standards.

This study was funded by NOAA, and conducted by TERC, Inc. TERC is an educational non-profit based in Cambridge, Massachusetts. TERC specializes in innovative science, math and technology education, and has conducted numerous educational research and policy studies. Its Center for Earth and Space Science Education has extensive experience and expertise in this field, and has worked with several states in reviewing and revising their Earth science education standards.

Products From This Study

We produced three products, each serving a unique purpose. They are accessible at: www.oesd.noaa.gov and www.terc.edu.

1. **Full Report –** The full report (this document) presents a narrative discussion of the findings, along with detailed reports for each criterion. It also includes an appendix with more detailed analysis of the ocean literacy standards.

2. **Annotated State Standards –** The annotated standards documents for each state, in PDF format, containing categorized bookmarks of all the highlighted standards analyzed in this study.

3. **Searchable Database –** A searchable database contains all of the standards statements analyzed in this study. We provide tab-delimited and FileMaker Pro© versions of the database for download.

Review Criteria

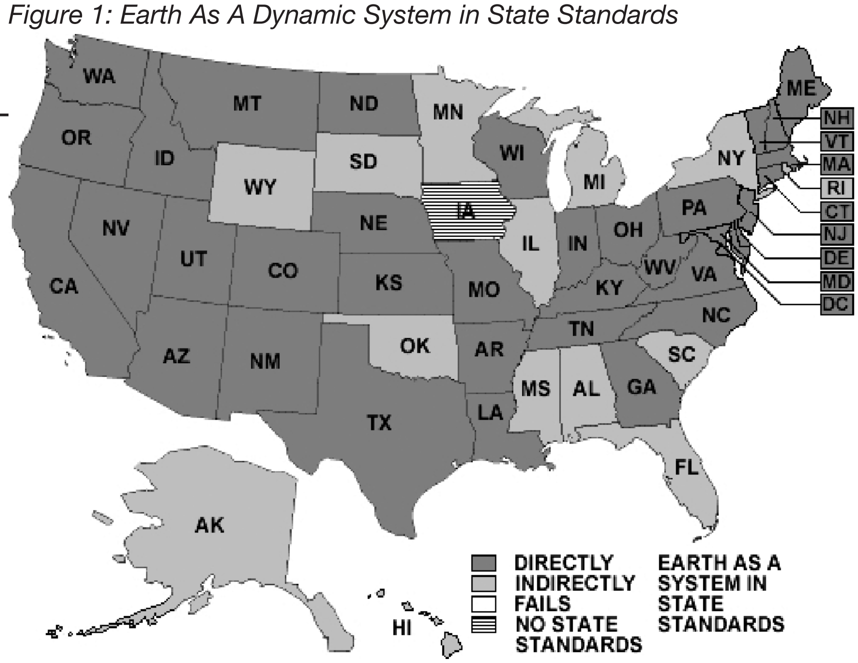
Understanding Earth as an integrated system of multiple components and processes is the dominant paradigm in Earth and space science research today. This portion of the study examined the degree to which this unifying principle is articulated in state Earth and space science standards. Understanding Earth as system necessitates that students not learn about Earth and space science as a set of disconnected and unrelated micro-concepts, but rather as a whole system with complex interconnections between the geosphere, hydrosphere, atmosphere and biosphere. Major concepts exemplifying this review criteria include: Earth as a complex system of interconnected components and processes; interactions between and within the hydrosphere, geosphere, atmosphere, and biosphere; geo-chemical cycles; interactions and processes between Earth and the solar system; energy transfer and dynamics; and modeling as a tool to understand systems.

Earth As A Dynamic System in State Standards

Every state, with the exception of Iowa, which does not have a single set of statewide standards, incorporates a systems-based perspective to some extent in its Earth science standards. Most states (n = 35) directly articulate systems-based concepts into their standards. This pervasiveness of systems thinking across the states is probably attributable to the centrality of systems-based thinking in The National Science Education Standards (NRC, 1996) and in the Benchmarks for Scientific Literacy (AAAS, 1993), both of which have significantly informed the development of most states' standards.

National Grade B+ (3.4)[2]

Figure 1: Earth As A Dynamic System in State Standards



Earth As A Dynamic System

Exemplary Earth-As-A-Dynamic-System State Standards

In Washington state, systems-based thinking is a key unifying theme within the science standards. Washington's standards treat Earth as a system from early elementary grades through high school. Students develop increasing depth of knowledge about interacting systems and are required to perform progressively more sophisticated research on systems as they advance. Listed below is a selection of Washington's excellent systems standards.

❖ Construct a model that demonstrates understanding of Earth's structure as a system made of parts (e.g., solid surface, water, atmosphere). (Washington: Grade 3-5)

❖ Describe the interactions among the components of Earth's systems (i.e., the core, the mantle, oceanic and crustal plates, landforms, the hydrosphere and atmosphere). (Washington: Grade 6-8)

❖ Analyze the relationship between weather and climate and how ocean currents and global atmospheric circulation affect weather and climate. (Grade 6-8)

❖ Explain how ocean currents influence the atmosphere in terms of weather and climate. (Washington: Grade 6-8)

❖ Explain the causes of atmospheric circulation and oceanic currents (e.g., prevailing winds are the result of hot tropical regions, cold polar regions, and Earth's spin). (Washington: Grade 6-8)

❖ Analyze the patterns and arrangements of Earth systems and subsystems including the core, the mantle, tectonic plates, the hydrosphere, and layers of the atmosphere. (Washington: Grade 9-10)

❖ Correlate Earth's surface features to observable weather patterns (e.g., rain shadow, deserts, rain forest). (Washington: Grade 9-10)

❖ Describe the processes that cause the movement of material in Earth's systems (e.g., pressure differences that cause convection resulting in winds, mantle movement, and ocean currents; erosion and deposition). (Washington: Grade 9-10)

❖ Explain how energy transfers and transformations among the atmosphere, hydrosphere, and landforms affect climate and weather patterns. (Washington: Grade 9-10)

[2] National grades for each of the review criteria, except ocean literacy, were calculated by assigning a letter grade and corresponding grade point value to each of the three possible ratings —Directly/A/4.0, Indirectly/C/2.0, and Failing/F/0.0—and then calculating the grade point average of all states for each review criteria using a traditional 4.0 grading scale. The ocean literacy national grade was calculated using a grading scale tied directly to the analysis of thirty-five fundamental concepts. This grading process is described in the ocean literacy section of this report. Iowa was not included in the grade calculations as this state does not have statewide standards.

Earth As A Dynamic System

Additional examples of excellent systems-based standards from other states follow.

- ❖ Recognize and describe that earth sciences address planet-wide interacting systems, including the oceans, the air, the solid earth, and life on Earth, as well as interactions with the Solar System. (Indiana: High School)
- ❖ Students demonstrate an understanding about how Earth systems and processes interact in the geosphere resulting in the habitability of Earth. This includes demonstrating an understanding of the composition of the universe, the solar system and Earth. In addition, it includes understanding the properties and the interconnected nature of Earth's systems, processes that shape Earth and Earth's history. Students also demonstrate an understanding of how the concepts and principles of energy, matter, motion and forces explain Earth systems, the solar system and the universe. Finally, they grasp an understanding of the historical perspectives, scientific approaches and emerging scientific issues associated with Earth and space sciences. (Ohio: Grades K-12)
- ❖ Explaining how the physical and chemical processes of the Earth alter the crust (e.g. hydrologic cycle, solar energy, element cycling). (Rhode Island: Grade 9-11)
- ❖ Explain how geological and ecological processes interact through time to cycle matter and energy, and how human activity alters the rates of these processes (e.g., fossil fuel formation and combustion). (Georgia)
- ❖ Explain how the transfer of energy through radiation, conduction, and convection contributes to global atmospheric processes, such as, storms, winds, and currents. (Massachusetts: Grades High School)
- ❖ The geosphere, hydrosphere, and atmosphere are continually interacting through processes that transfer energy and Earth's materials. (Missouri: Grade 9-11)
- ❖ Use computer modeling/ simulations to predict the effects of an increase in greenhouse gases on earth systems (e.g. earth temperature, sea level, atmosphere composition). (Rhode Island: Grade 9-11)

Space-Age Perspectives

Review Criteria

Space-age capabilities and technologies have transformed the study and understanding of Earth systems. Data acquired over the past forty years from satellites, manned spacecraft, robotic instruments, and inter-planetary probes have revolutionized our understanding of Earth's systems, the solar system, and the universe. Space-age technologies have similarly helped scientists better understand interactions between Earth and the solar system. Space-age research technologies enable scientists to accurately monitor and model changes in Earth's systems over time.

This portion of the analysis looked for standards statements that contained the following types of concepts or student use of space-age data resources: space-age technologies have revolutionized the study of Earth, the solar system, and the universe; students access, interpret, and analyze data collected from space-borne instruments; students compare or verify ground-based observations with satellite data; models of Earth system processes can be developed from satellite data; satellites collect data used to monitor and predict weather, climate, and environmental conditions over short and long periods of time; telescopes, satellites, and robotic probes are used to explore and understand the solar system and the universe; and space-age technologies have changed humanities knowledge and perspectives of Earth, the solar system, and the universe.

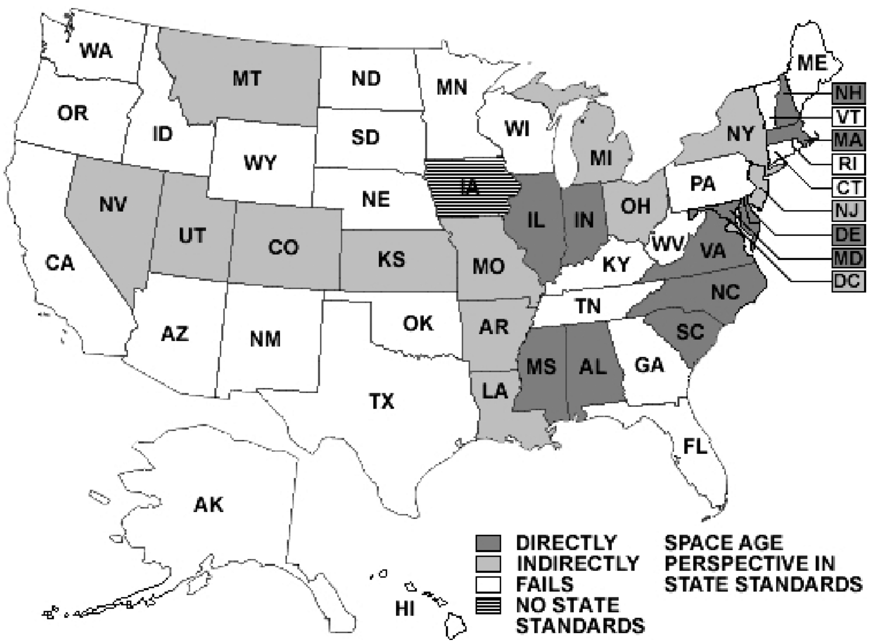
Space-Age Perspectives in State Standards

More than half of the states (n = 26) have standards that fail to incorporate the space-age perspective. Surprisingly, several states that are key players in the space industry (Florida, Texas, and California) fail to feature the space-age perspective in their Earth science standards. One fourth of the states (n = 11) directly feature a space-age perspective. Slightly less than a quarter of all states (n = 13) have statements that indirectly articulate components of the space-age perspective.

Space-Age Perspectives

National Grade – D+ (1.4)

Figure 2: Space-Age Perspectives in State Standards



Exemplary State Standards for Space-Age Perspectives

- ❖ Technology allows scientists to explore the Solar System and to observe and measure features and structures of the Earth, Moon, and other solar objects. (Delaware: Grade 4-5)
- ❖ Describe the use and benefits of land based light telescopes, radio telescopes, spectrophotometers, satellites, manned exploration, probes, and robots to the study of Earth Space Science. (New Hampshire: Grade 9-11)
- ❖ Describe the impact of technology on the study of the Earth, the solar system, and the universe. (Louisiana: Grade 9-12)
- ❖ Describe data gathering and observation technologies and explain how they are used to explore the solar system and beyond. (New Jersey: Grade 9-12)
- ❖ Discuss how manned and unmanned space vehicles can be used to increase our knowledge and understanding of the universe. (Indiana: High School)

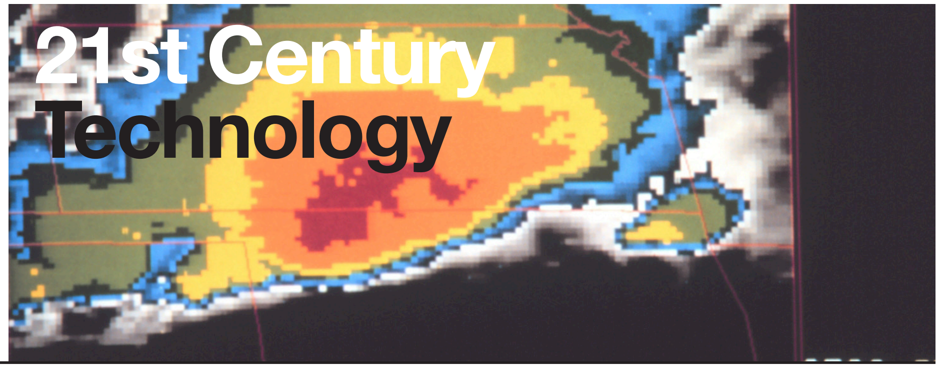
Space-Age Perspectives

- ❖ Discuss the role of sophisticated technology, such as telescopes, computers, space probes, and particle accelerators, in making computer simulations and mathematical models in order to form a scientific account of the universe. (Indiana: High School)
- ❖ Explain how scientists obtain information about the universe by using technology to detect electromagnetic radiation that is emitted, reflected or absorbed by stars and other objects. (Indiana: Grade 12)
- ❖ Recognize features of the Earth as viewed by astronauts in orbit and as transmitted by scientific instruments on satellites and spacecraft. (New Hampshire: Grade 3-4)
- ❖ Study photographs or satellite images of Earth to identify unique features of our planet (e.g., continents, land forms, weather systems). Discuss what can be learned and predicted by studying this information. (Delaware: Grade 4-5)
- ❖ Identify and distinguish between various landforms, using a map and/or digital images. (New Hampshire: Grade 5-6)
- ❖ Use a variety of resources (e.g., NASA photographs, computer simulations, satellite images) to compare the physical properties (e.g., size, surface features, tilt of axis) of the planets as well as their similarities and differences. (Delaware: Grade 6-8)
- ❖ Close-up pictures and data received from space probes allow scientists to compare the physical properties of planets (e.g., size, surface features, number of rings) and to speculate about conditions on other planets. (Delaware: Grade 6-8)
- ❖ Explain that satellites can be used to view and track storms and Earth events, such as hurricanes and wild fires. (New Hampshire: Grade 5-6)
- ❖ Read, interpret, and analyze a combination of ground-based observations, satellite data, and computer models to demonstrate Earth systems and their interconnections. (Massachusetts)
- ❖ Identifying new instrumentation and communication technologies needed for space information gathering. Examples: Mars Exploration Rover, Cassini spacecraft and Huygens probe, Gravity Probe B. (Alabama)
- ❖ Relate how evidence from advanced technology, applied to scientific investigations (e.g., large telescopes and space-borne observatories), has dramatically impacted our understanding of the origin, size, and evolution of the universe. (Montana: Grade 12)

Space-Age Perspectives

- ❖ Discuss ways society has benefited from space exploration (e.g., production of new materials, development of sophisticated computers, advances in satellite communication technology). Research the economic implication of the space program, and debate the pros and cons of future space exploration. (Delaware: Grade 6-8)
- ❖ Apply scientific inquiries or technological designs to examine the changing perspective of the Earth in space, documenting the changes in public perception of the Earth since the space program began, or researching the technologies that have broadened the information known about the earth and its resources. (Illinois: Grade 9-10)

21st Century Technology



Review Criteria

Twenty-first century technologies have revolutionized Earth and space science research. Many of the same tools that scientists use, such as visualization software, geographic information systems (GIS), real-time and archived data sets, and powerful computer analysis tools are also nearly universally accessible to students. The availability of these technologies allows them to play a pivotal role in revolutionizing K-12 Earth and space science education.

For this study, 21st century technology in Earth and space science education is typified by the following concepts and perspectives: Internet access to real-time and archived data sets and remotely-sensed satellite imagery and data visualizations; software data analysis tools capable of analyzing these data; computer modeling programs; use of these data and tools to solve authentic research questions and problems; and Internet-based communications and data-sharing technologies.

This review criterion is closely tied to the space-age perspective criteria discussed previously in that many of the data collection technologies are space-borne instruments. For the purposes of this analysis, 21st century technologies refers more specifically to the data, tools, and access methods that students utilize than to the fact that many of these data sets come from space-age instruments.

21st Century Technology in State Standards

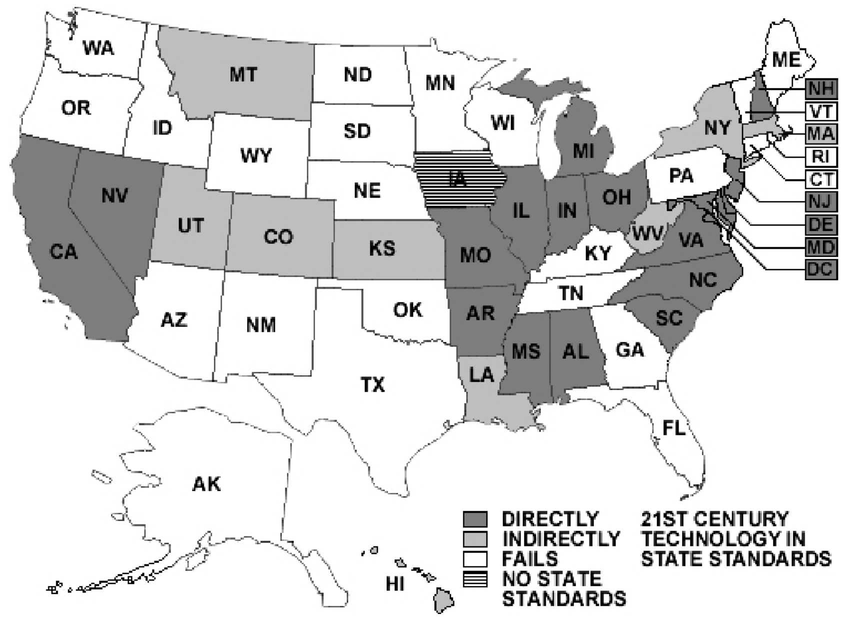
One-third (n = 18) of the states have standards that clearly include 21st century technologies as a key component of their Earth and space science courses. Several states within this top ranked group have excellent sets of standards related to this review criterion. New Hampshire's standards clearly establish learning goals that illustrate the role of technology in Earth science. Delaware's standards articulate progressively sophisticated levels of understanding regarding the use of modern technology in Earth science research over the K-12 grade span.

On the other extreme, slightly less than half of the states (n = 23) do not have standards addressing the uses of 21st century technologies in Earth science research. Roughly one-fifth of the states (n = 9) do incorporate 21st century technologies concepts into their standards, but only to the point of earning an indirect ranking.

21st Century Technology

National Grade – C- (1.8)

Figure 3: 21st Century Technology in State Standards



Exemplary State Standards for 21st Century Technology

New Hampshire's standards clearly articulate the important role of 21st century technology in modern Earth science, beginning at the elementary level and progressively developing more sophisticated understandings up through high school.

❖ The growth of scientific knowledge in Earth Space Science has been advanced through the development of technology and is used (alone or in combination with other sciences) to identify, understand and solve local and global issues. (New Hampshire: Grades K-12)

❖ Use a variety of information access tools to locate, gather, and organize potential sources of scientific information to answer questions. (New Hampshire: Grade 8)

❖ Collect real-time observations and data, synthesizing and building upon existing information (e.g., online databases, NOAA, EPA, USGS) to solve problems. (New Hampshire: Grade 8)

❖ Describe ways in which technology has increased our understanding of the universe. (New Hampshire: Grades 9-11)

❖ Understand that technology is designed with a particular function in mind, and principles of Earth Space science are useful in creating technology for the Earth space sciences. (New Hampshire: Grades 9-11)

21st Century Technology

❖ Describe the use and benefits of Land based Light Telescopes, radio telescopes, spectrophotometers, satellites, manned exploration, probes, and robots to the study of Earth Space Science. (New Hampshire: Grades 9-11)

❖ Explain how scientists study the Earth using computer-generated models and observations from both land based sites and satellites, and describe the value of using these tools in unison. (New Hampshire: Grades 9-11)

❖ Recognize the importance of technology as it relates to science, for purposes such as: access to space and other remote locations, sample collection and treatment, measurement, data collection, and storage, computation, and communication of information. (New Hampshire: Grades 11-12)

Additional examples of excellent standards for 21st century technology follow.

❖ Technologies, including computers, probeware, and global positioning systems (GPS), are used to collect, analyze, and report data and to demonstrate concepts and simulate experimental conditions. (Virginia: Grades K-12)

❖ Explain how technology designed to investigate features of the Earth's surface impacts how scientists study the Earth. (New Jersey: Grades 7-8)

❖ Explain that technology is essential to science for such purposes as measurement, data collection, graphing and storage, computation, communication of information, and access to outer space and other remote locations. (District of Columbia: Grade 6)

❖ Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data. (California: Grades 9-12)

❖ Analyze the impact of modern technology on the study of the Earth and universe (telescopes, space probes, robotic arms, weather satellites, Doppler radar, sonar, seismographs). (Arkansas: Grades 9-12)

❖ Explain how technology and computer modeling have increased our understanding of the universe. (South Carolina: Grades K-12)

❖ Use computer modeling/ simulations to predict the effects of an increase in greenhouse gases on earth systems (e.g. earth temperature, sea level, atmosphere composition). (Rhode Island: Grades 9-11)

❖ Utilize data gathered from emerging technologies (e.g., geographic information systems (GIS) and global positioning systems (GPS)) to create representations and describe processes of change on the Earth's surface. (New Jersey: Grades 7-8)

Inquiry-Based Approaches

Review Criteria

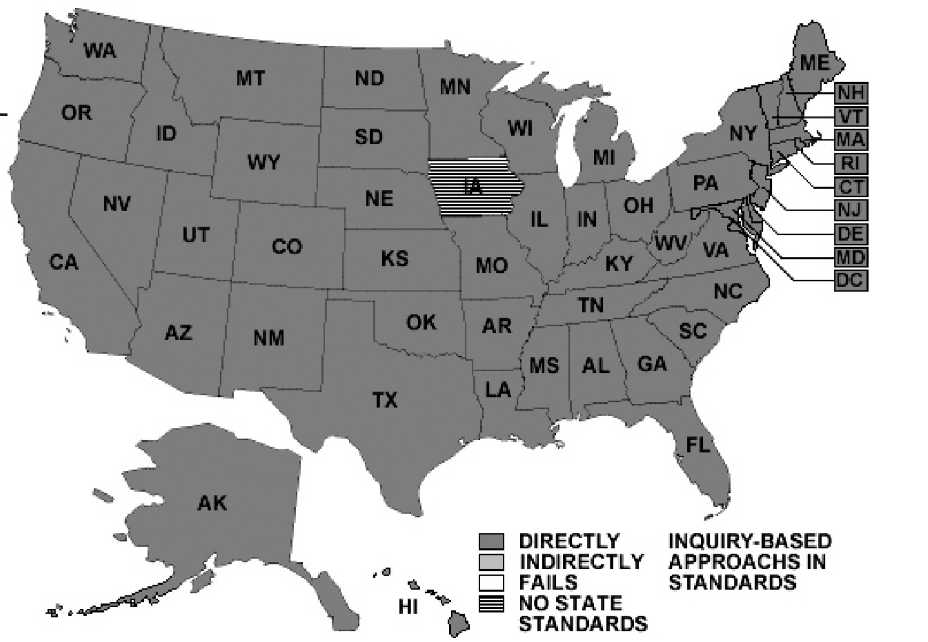
The inquiry-based approaches portion of this study reviewed standards that articulate Earth and space science teaching and learning as a process of inquiry, exploration, and discovery. Through inquiry-based approaches, students discover knowledge and develop thinking skills via laboratory, field, and Internet-based investigations. Students learn content knowledge and develop deeper understandings of scientific inquiry. These experiences mirror the work of Earth and space scientists and provide an essential foundation for workforce development.

Key elements of an inquiry-based approach include: investigation of authentic, real-life questions—preferably questions generated by the students themselves as a result of their experiences and observations; investigations designed and completed by the students; data collected from open-ended experimental investigations, field studies and observational studies; interactive exploration of satellite imagery and data visualizations; analysis, synthesis, and summarization of research data—all wrapped in to developing understanding about the nature of scientific inquiry as the process used to understand natural phenomena.

Inquiry Based Approaches in State Standards

Teaching science through the process of inquiry is a pervasive educational strategy directly articulated in all of the state science standards.

National Grade – A (4.0)



Inquiry-Based Approaches

Significant variation exists in the depth and specificity to which states articulate their inquiry-based learning standards. Some states, such as Utah and Washington fully embrace inquiry-based approaches as a primary means of student learning.

National Grade – A (4.0)
In giving this grade, we raise an important caveat. Most state standards separate "inquiry" standards from "content" standards. While this provides clarity on the nature of inquiry, there are significant gaps in applying these standards to the content domains. For example, few states make explicit reference in their Earth science standards to the use of satellite images and data visualizations as an essential tool for modern Earth science. These resources should serve a central role for inquiry in Earth science and yet they are often absent from the formal Earth science standards. Hence, states need to specifically articulate how inquiry applies to Earth science and not simply assume that districts and teachers will automatically make the connection.

Exemplary State Standards for Inquiry-Based Learning

The following exemplary inquiry standards illustrate the open-ended nature of student investigations, even when a specific Earth science investigation topic is identified in the standard. Each of these standards places the student in the role of the research scientist.

- ❖ Select appropriate tools and technological resources needed to gather, analyze, and interpret data. (Alabama: Grade 1)
- ❖ Design and safely implement an experiment, including the appropriate use of tools and techniques to organize, analyze, and validate data. (Hawaii: High School)
- ❖ Collect real-time observations and data, synthesizing and building upon existing information (e.g., online databases, NOAA, EPA, USGS) to solve problems. (New Hampshire: Grade 8)
- ❖ Design tests to study the effects of physical processes (freezing and thawing of water, erosion) and chemical processes (oxidation, acidification) on the structure of rocks, and speculate on the impact of climate, topography, and airborne and water pollutants on these processes. (Delaware: Grade 6-8)
- ❖ Use appropriate technology solutions (e.g., computer, CBL, probe interfaces, software) to measure and collect data; interpret data; analyze and/or report data; interact with simulations; conduct research; and present and communicate conclusions. (West Virginia: Grade 8-12)

Inquiry-Based Approaches

- ❖ Use data from a variety of sources (e.g., NOAA, NASA, EPA, U of DE, USGS, AGU) to correlate significant changes in local and global weather (global warming, El Niño) to interactions of ocean systems. (Delaware: Grade 6-8)
- ❖ Use technology (e.g., maps, satellite imagery, instrumentation) to locate possible sources of environmental pollution. Compare sources with meteorological data to locate the probable origin of regional contamination. (Delaware: Grade 6-8)
- ❖ Report and display the process and findings of inquiry investigation, presenting oral or written final report for peer review, generating further questions for alternative investigations or procedural refinements, or evaluating other investigations for consolidation/refinement of procedures or data explanation. (Illinois: Grade 6-8)
- ❖ Interpret and represent analysis of results to produce findings, observing trends within data sets, evaluating data sets to explore explanations of outliers or sources of error, or analyzing observations and data which may support or refute inquiry hypothesis. (Illinois: Grade 6-8)
- ❖ Analyze scientific studies referenced in curricular investigations in life, environmental, physical, earth, and space sciences, reviewing experimental procedures or explanations for possible faulty reasoning or unproven statements (e.g., power line magnetic fields, abiogenesis models), distinguishing relationships of scientific theories, models, hypotheses, experiments, and methodologies, or distinguishing fact from opinion and science from pseudoscience. (Illinois: Grade 9-10)
- ❖ Use models to identify and predict cause-effect relationships (e.g., effect of temperature on gas volume, effect of carbon dioxide level on the greenhouse effect). (Nevada: Grade 9-12)

Ocean Literacy

Review Criteria

This portion of the study examined the degree to which state standards address the "essential principles" and "fundamental concepts" of ocean literacy as defined in *Ocean Literacy: The Essential Principles and Fundamental Concepts of Ocean Sciences* (Cava et al., 2005). The seven essential principles of ocean literacy are as follows.

1. The Earth has one big ocean with many features.
2. The ocean and life in the ocean shape the features of Earth.
3. The ocean is a major influence on weather and climate.
4. The ocean makes the Earth habitable.
5. The ocean supports a great diversity of life and ecosystems.
6. The ocean and humans are inextricably interconnected.
7. The ocean is largely unexplored.

A detailed subset of supporting "fundamental concepts" underlies each these seven essential principles. The entire set of ocean literacy essential principles and fundamental concepts is detailed in Appendix A of this report.

This study examined thirty-five of the forty-five fundamental concepts. We did not analyze the ten fundamental concepts underlying essential principle number five, "The ocean supports a great diversity of life and ecosystems." These ten concepts were not examined because this study focused on Earth science standards rather than biology standards.

In addition to this general summary, Appendix B of this report provides a comprehensive analysis of our findings regarding the current status of ocean literacy principles and concepts within states standards.

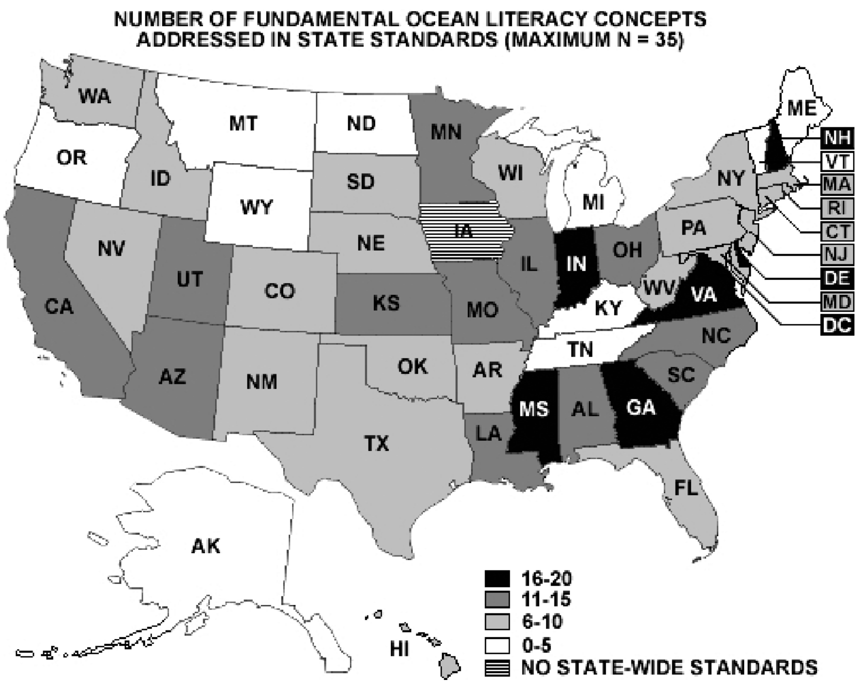
Ocean Literacy in State Standards

Across the nation, fundamental ocean literacy concepts are not adequately incorporated into state science standards. Forty-seven states, plus the District of Columbia, incorporate at least a few ocean literacy concepts in their science standards. However, no state addresses more than twenty of the thirty-five fundamental ocean literacy concepts examined in this study. States with the greater number of ocean literacy concepts addressed in their standards (16-20) are all located east of the Mississippi River. Each of these top ranked states are ocean or Great Lake coastal states. Three states—Iowa, Vermont, and Wyoming—do not address any of the ocean literacy concepts in their standards. On average, the twenty-four coastal states (including the District of Columbia), address ocean literacy concepts only slight more frequently than the twenty-seven inland states (10.8 fundament concepts verses 8.5).

Ocean Literacy

National Grade – D (1.0)[3]

Figure 5: Number of Fundamental Ocean Literacy Concepts Addressed in State Standards



Exemplary Standards for Ocean Literacy

- ❖ Three-fourths of its surface is covered by a relatively thin layer of water (some of it frozen), and the entire planet is surrounded by a relatively thin blanket of air. (Rhode Island: Grade 8)
- ❖ Explain special properties of water (e.g., high specific and latent heats) and the influence of large bodies of water and the water cycle on heat transport and therefore weather and climate. (District of Columbia)
- ❖ Recognize the relationships between the tides and the phases of the moon, and use tide charts and NOAA information to describe them. (New Hampshire)
- ❖ Identify the reservoirs of Earth's water cycle (e.g., ocean, ice caps/glaciers, atmosphere, lakes, rivers, biosphere, groundwater) locally and globally, and graph or chart relative amounts in global reservoirs. (Utah)

[3]The national ocean literacy grade was determined by assigning a letter grade to each state according to the following grading scale and then using a traditional 4-point scale for the assigned letter grade to determine the national ocean literacy grade point average. Ocean literacy grading scale—(letter grade/number of fundamental concepts addressed): A/28-35, B/21-27, C/13-20, D/7-13, F/0-6.

- ❖ Design and build models to demonstrate how wind and water shape the land. Explain how erosional agents such as water and ice produce distinctive landforms (e.g., water and bad lands, ice and glacial valleys, waves and sea cliffs). (Delaware: Grades 6-8)
- ❖ Analyze the mechanisms that produce the various types of shorelines and their resultant landforms: • Nature of underlying geology. • Long and short term sea-level history. • Formation and breaking of waves on adjacent topography. • Human impact. (North Carolina)
- ❖ Relate the characteristics and behavior of mechanical waves to earth processes (e.g., explain the formation of water waves as a function of wind velocity, duration, and fetch). (West Virginia: Grade 10)
- ❖ Explain the relationships of the oceans to the lithosphere and atmosphere (e.g., transfer of energy, ocean currents and landforms). (Ohio: Grade 9)
- ❖ Explain that much of the heat from the sun is absorbed by the land and oceans and then is released into the atmosphere. (District of Columbia)
- ❖ Describing how differential heating of the oceans affects ocean currents which in turn influence weather and climate. (Rhode Island: Grades 5-6)
- ❖ Recognize and explain that heat energy carried by ocean currents has a strong influence on climate around the world. (Indiana: Grade 7)
- ❖ Explain how the transfer of energy through radiation, conduction, and convection contributes to global atmospheric processes, such as, storms, winds, and currents. (Massachusetts)
- ❖ Students will understand how the distribution of land and oceans affects climate and weather. a. Demonstrate that land and water absorb and lose heat at different rates and explain the resulting effects on weather patterns. b. Relate unequal heating of land and water surfaces to form large global wind systems and weather events such as tornados and thunderstorms. c. Relate how moisture evaporating from the oceans affects the weather patterns and the weather events such as hurricanes. (Georgia)
- ❖ Investigate how thermal energy transfers in the world's oceans impact physical features (e.g., ice caps, oceanic and atmospheric currents) and weather patterns. (Ohio: Grade 12)
- ❖ The Earth's atmosphere has changed over time. For example, the dramatic changes in Earth's atmosphere (i.e., introduction of O2) which was affected by the emergence of life on Earth. (Kansas: Grades 8-12)

Ocean Literacy

- ❖ Students know how the composition of Earth's atmosphere has evolved over geologic time and know the effect of out gassing, the variations of carbon dioxide concentration, and the origin of atmospheric oxygen. (California)
- ❖ Explain how the oceans affect other processes on Earth. (Mississippi) (3A and others)
- ❖ The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include: a) physical and chemical changes (tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations): b) importance of environmental and geologic implications; c) systems interactions (density differences, energy transfer, weather, and climate); d) features of the sea floor (continental margins, trenches, mid-ocean ridges, and abyssal plains) as reflections of tectonic processes; e) economic and public policy issues concerning the oceans and the coastal zone including the Chesapeake Bay: and g) the importance of protecting and maintaining water resources. (Virginia: Grade 11)
- ❖ Analyze the physical and biological dynamics of the oceans. a. Describe the physical dynamics of the oceans (e.g., wave action, ocean currents, El Niño, tides). b. Determine how physical properties of oceans affect organisms (e.g., salinity, depth, tides, temperature). c. Model energy flow in ocean ecosystems. d. Research and report on changing ocean levels over geologic time, and relate changes in ocean level to changes in the water cycle. e. Describe how changing sea levels could affect life on Earth. (Utah: Grades 9-12)
- ❖ The understanding of global and local changes that result from the interactions of ocean systems has increased substantially as a result of continuous advances in science and technology. (Delaware: Grades 9-12)

Atmosphere, Weather, and Climate

Review Criteria

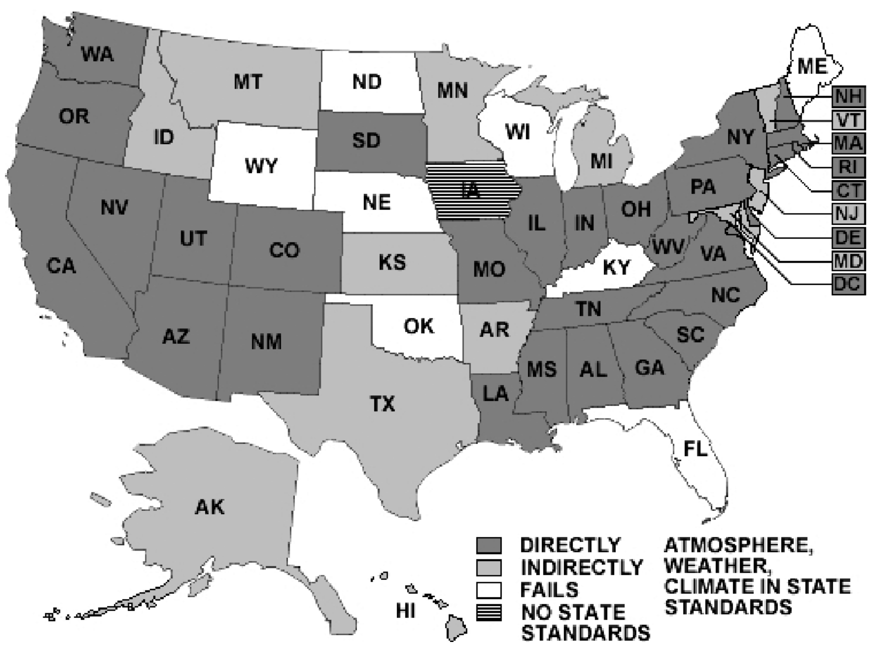
This portion of the study examined each state's treatment of atmosphere, weather, and climate concepts. Key conceptual components within this domain include: the processes that cause and influence weather; physical characteristics of water and its role in energy transfer processes; uneven heating and cooling of the Earth's surface; global wind circulation patterns; role of radiation, convection, and conduction in weather; tools and processes of weather monitoring and prediction; causes of seasons; climate variability and change over short and long time periods; greenhouse effect; climatic zones; modeling of climate change; and human influence on weather and climate. Of particular importance are concepts that address atmosphere, weather and climate in terms of interacting Earth systems.

Atmosphere, Weather and Climate in State Standards

Forty-two states directly (n = 30) or indirectly (n = 12) address atmosphere, weather and climate within their standards. Eight states have standards that fail to adequately address atmosphere, weather or climate concepts.

National Grade - C+ (2.9)

Figure 6: Atmosphere, Weather, and Climate in State Standards



Atmosphere, Weather, and Climate

The fact that every person in every school district is directly affected on a daily basis by weather and climate should elevate deep understanding of weather and climate to a priority in Earth science education. Yet, surprisingly, eight states fail to do so. Even more alarming is that some of the states with the most severe weather are part of this poorly rated group. For example, Florida Earth science standards do not even mention hurricanes.

Exemplary State Standards for Atmosphere, Weather & Climate

These standards address key atmosphere concepts. They show the systematic interactions involved in atmospheric processes and illustrate scientific tools and methods used in gaining understanding of the atmosphere.

- ❖ Explain how uneven heating at the equator and polar regions creates atmospheric and oceanic convection currents that move heat energy around Earth. (Utah: Grades 7-12)
- ❖ Explain how different regions receive different amounts of solar heating because of their latitude, clouds, surface water ice, and other variables. Understand that this results in large-scale convective air flow and weather patterns. (District of Columbia: Grades K-12)
- ❖ Explain special properties of water (e.g., high specific and latent heats) and the influence of large bodies of water and the water cycle on heat transport and therefore weather and climate. (District of Columbia: Grades K-12)
- ❖ Observe and explain how parts are related to other parts in systems such as weather systems, solar systems, and ocean systems including how the output from one part of a system (in the form of material, energy, or information) can become the input to other parts (e.g., El Niño's effect on weather). (Georgia: Grades 6-8)
- ❖ Relate how weather patterns are the result of interactions among ocean currents, air currents, and topography. (Utah: Grades 7-12)
- ❖ Use weather maps and reports over an extended period of time to show the effects of uneven heating and cooling of the earth's surface on weather. Discuss the role of radiation, convection, and conduction in weather changes. (Delaware: Grades K-12)
- ❖ Research ways the biosphere, hydrosphere, and lithosphere interact with the atmosphere (e.g., volcanic eruptions putting ash and gases into the atmosphere, hurricanes, changes in vegetation). (Utah: Grades 7-12)

Atmosphere, Weather, and Climate

- ❖ Describe the development and dynamics of climatic changes over time corresponding to changes in the Earth's geography (continental drift), orbital parameters (the Milankovitch cycles), and atmospheric composition. (District of Columbia: Grades K-12)
- ❖ Trace ways in which the atmosphere has been altered by living systems and has itself strongly affected living systems over the course of Earth's history. (Utah: Grades 7-12)
- ❖ Use computer modeling/ simulations to predict the effects of an increase in greenhouse gases on earth systems (e.g. earth temperature, sea level, atmosphere composition). (Rhode Island: Grades K-12)
- ❖ Compare the rate at which CO2 is put into the atmosphere to the rate at which it is removed through the carbon cycle. (Utah: Grades 7-12)

Environmental Literacy

Review Criteria

Environmentally literate students apply content specific knowledge and problem-solving skills to make informed and responsible decisions regarding stewardship of planet Earth. Environmental issues provide the real-life context that allows students to synthesize and apply their Earth science knowledge and research skills in a comprehensive fashion.

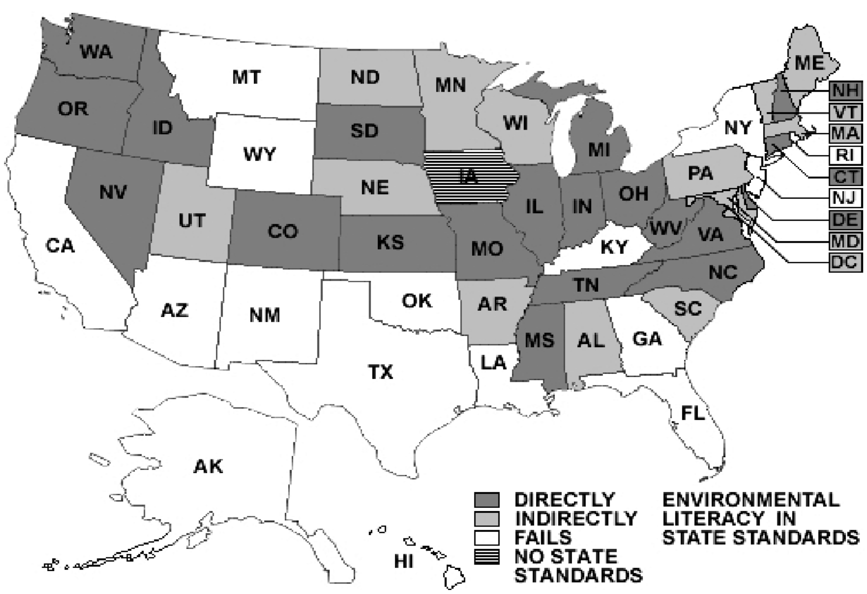
In this portion of the study, we looked for the following content and skill statements that describe an environmentally literate citizen. An environmentally informed citizen knows that: Earth has finite resources; humanity utilizes Earth resources and causes both short-term and long-term impacts to Earth's systems; space-age and other 21st century technologies can be used to study and model environmental changes; and it is important that people make scientifically informed and responsible decisions regarding the management of Earth's resources and systems.

Environmental Literacy in State Standards

Inclusion of environmental literacy concepts varies considerably across the country. Twenty states (40%) directly feature environmental literacy in their standards. Fourteen states (27%) indirectly address some environmental literacy concepts. One-third (n = 16) do not articulate environmental literacy concepts within their science standards to a mentionable degree. (It should be noted that this study specifically reviewed Earth science and general science standards, not environmental science course standards.)

National Grade – C (2.2)

Figure 7: Environmental Literacy in State Standards



Environmental Literacy

Many environmental literacy standards are inquiry-based research activities in which students collect data on an authentic, real-life environmental topics. Students use their data to make predictions about the severity of the environmental issue and propose solutions. These types of environmental literacy research activities represent capstone learning activities since they require students to apply content knowledge, modern research technologies, and inquiry based research skills.

Several states require students to examine evidence for climate change and associated environmental impacts. Air and water pollution issues are commonly considered topics within environmental related standards. Some states have standards addressing environmental issues specific to their state. For example, in Mississippi, students examine the effects of urban areas on aquatic systems. Statements specifically focusing on ocean and coastal environmental issues were rarely present in state standards.

Exemplary State Standards for Environmental Literacy

- ❖ Understand how humans depend on the natural environment and can cause changes in the environment that affect humans' ability to survive. (Washington: Grades 3-5)
- ❖ Explain how human activity (including conservation efforts and pollution) has affected the land and the oceans of Earth. (South Carolina: Grade 5)
- ❖ Explore evidence that human-caused changes have consequences for the immediate environment as well as for other places and future times. (New Hampshire: Grade 6)
- ❖ Analyze how human societies' use of natural resources affects the quality of life and the health of ecosystems. (Washington: Grades 6-8)
- ❖ Predict the potential impact of human activities on long-range changes in surface and climate of Earth. (Example: rain forest, clear cutting, El Niño) (South Dakota: Grade 8)
- ❖ Analyze the effects human activities have on Earth's capacity to sustain biological diversity. (Washington: Grades 9-10)
- ❖ Explain how human activities affect Earth's capacity to sustain biological diversity (e.g., global warming, ozone depletion). (Washington: Grades 9-10)
- ❖ Predict the effect of change on the other sphere when given a scenario describing how the composition of the atmosphere, hydrosphere, or geosphere is altered. (Missouri: Grades 9-12)

Environmental Literacy

❖ Describe possible consequences of reducing or of eliminating some of Earth's natural resources. (South Dakota: Grades 9-12)

❖ Investigate how human activity has changed the land, ocean, and atmosphere of Earth. (Example: forest cover, chemical usage) (South Dakota: Grades 9-12)

❖ Explain ways in which humans have had a major effect on other species (e.g., the influence of humans on other organisms occurs through land use, which decreases space available to other species and pollution, which changes the chemical composition of air, soil and water). (Ohio: Grade 11)

❖ Evaluate the effects of urbanization on aquatic ecosystems. (Mississippi: Grades K-12)

❖ Investigate the relationship between the use of different natural resources and the effect of their use on the environment. (South Dakota: Grade 3)

❖ Design environmental investigations to answer particular questions. (New Hampshire: Grade 6)

❖ Investigate environmental and resource management issues at scales that range from local to national to global. (New Hampshire: Grade 6)

❖ Use technology (e.g., maps, satellite imagery, instrumentation) to locate possible sources of environmental pollution. Compare sources with meteorological data to locate the probable origin of regional contamination. (Delaware: Grades 6-8)

❖ Given a time series of data on atmospheric composition, identify changes that occur in the atmosphere over the period and predict possible future scenarios (e.g., ozone depletion, increased greenhouse effect, acid rain, volcanic dust plumes). (Delaware: Grades 6-8)

❖ Create, use and evaluate models to understand environmental phenomena. (New Hampshire: Grade 11)

❖ Analyze environmental issues such as water quality, air quality, hazardous waste, and depletion of natural resources. (New Hampshire: Grade 11)

❖ Analyze environmental issues such as water quality, air quality, hazardous waste, and depletion of natural resources. (New Hampshire: Grade 11)

❖ Investigate and describe how human actions may impact the dynamic equilibrium of global systems (e.g., global warming, ozone depletion). (Nevada: Grades 9-12)

❖ Provide evidence (e.g., melting glaciers, fossils, desertification) that supports theories of climate change due to natural phenomena and/or human interactions. (Missouri: Grades 9-12)

❖ Identify human activities that adversely affect the composition of the atmosphere, hydrosphere, or geosphere. (Missouri: Grades 9-12)

Conclusion and Recommendations

This study examined how well Earth science standards across the country incorporate seven forward-looking perspectives and approaches to K-12 Earth science education. These perspectives include four cutting edge "revolutionary" Earth science education approaches: Earth considered as a dynamic interactive system; Earth examined through the perspective of space-age tools; use of 21st century technologies in Earth science research; and application of inquiry-based approaches to teaching and learning about Earth science. Three criteria specifically tied to NOAA's principal areas of strategic responsibility complete the set of seven perspectives examined. These three NOAA-specific domains are: ocean literacy principles and concepts; atmosphere, weather, and climate content; and environmental literacy principals and applications.

These findings provide, for the first time, a detailed national picture, for a given point in time, of the degree to which modern Earth science perspectives are incorporated in standards. As such, these findings can be used as a benchmark to measure changes in standards over time. More importantly, this analysis can be used to help establish strategic steps for revolutionizing Earth systems science education.

As a whole, this study shows that there is great variation in the degree to which states currently incorporate modern Earth science perspectives into their science standards. Approaches and perspectives articulated by the National Science Education Standards (e.g. inquiry-based learning and system-based perspectives) were found to be commonly included within state standards. For example, we found that inquiry-based learning approaches are incorporated into every state's standards to some degree. While system-based thinking is a part of every state's standards, only thirty-five of the states directly presented the perspective of Earth as a set of interacting systems. We found that perspectives derived from traditionally covered subject areas (e.g. atmosphere, weather, and climate) were commonly present, but only satisfactorily so in two-thirds of the states. Recently emerging Earth science education approaches and perspectives, including 21st century technology and the space-age research perspective, were each found to be directly articulated in only a minority of the states' standards (18 and 11 states respectively). The ocean literacy principles and concepts, formulated in 2005, were not commonly present in most state's standards. The best seven states included only sixteen to twenty of the thirty-five different ocean literacy concepts analyzed. Twenty states directly articulated a fairly complete suite of environmental literacy perspectives, while seventeen states inadequately addressed environmental literacy concepts.

Conclusion and Recommendations

Recommendations for Improving Earth Science Education: Implementing the Revolution

- ❖ The concepts and approaches comprising the seven different review criteria should be viewed as an interrelated suite of perspectives, all supporting the core principles of quality Earth systems science education. Thus, any efforts to enhance inclusion of these perspectives into more state standards should focus not on one particular perspective, but simultaneously on multiple perspectives.
- ❖ The ocean literacy principles and concepts could be enhanced by better incorporating a systems perspective. More overt acknowledgement of the interactions between the ocean and other systems would help educators successfully incorporate ocean literacy concepts into the broader study of Earth sciences. Ocean literacy thus does not have to be viewed by educators as a replacement for other Earth science content, but instead as the conceptual glue that binds together many aspects of Earth science study. Ocean literacy might be better served and more readily incorporated into state standards if ocean concepts were highlighted within the context of systems dynamics and interactions, rather than being a standalone theme in the standards.
- ❖ Develop a comprehensive set of atmosphere, weather, and climate literacy principles and concepts, similar in format to the ocean literacy principles and concepts. Such a synthesis will provide clarity to states regarding the essential understandings and process of atmospheric sciences.
- ❖ Directly participate in state science standards revision processes. Public, academic, as well as state and federal agency input provides valuable perspectives that help the state develop a more thoughtful product. Recently revised state standards that involved participation by the authors of this report were found to better articulate the modern approaches to Earth science education than the old standards.
- ❖ Ensure that Web-based access to data and analysis tools are usable by the K-12 education community.
- ❖ Participate in the development of quality state and national science assessments. It is vital that these assessments cover Earth system science concepts; otherwise schools have little incentive to teach Earth system science to their students. Likewise, the format of the assessments should match the skill sets, data sets, and research tools deployed by students as they explore Earth systems science in their classroom learning.

Conclusion and Recommendations

- ❖ Demonstrate that modern “revolutionary” Earth science perspectives and approaches to teaching result in deep student learning of science concepts and thinking skills. This is a multi-step process. Step one involves developing and distributing model Earth science curricula that incorporate the revolutionary perspectives examined in this study. Next, the effectiveness of these curricula and approaches needs to be assessed via objective evaluation processes. After refinement, the final curricula must be widely distributed.
- ❖ Establish Earth system science as a science course widely viewed as being equally or more challenging as the classic high-school sciences of biology, chemistry, and physics.
- ❖ Tirelessly persist in promoting the revolution in Earth system science education with the understanding that improvements will occur incrementally.

Appendix A

Ocean Literacy: The Essential Principles and Fundamental Concepts of Ocean Sciences (Cava, et al., 2005)

Definition of Ocean Literacy

Ocean literacy is an understanding of the ocean's influence on you and your influence on the ocean. An ocean-literate person: understands the fundamental concepts about the functioning of the ocean; can communicate about the ocean in a meaningful way; and is able to make informed and responsible decisions regarding the ocean and its resources.

Essential Principles and Fundamental Concepts

1) The Earth has one big ocean with many features.

a. The ocean is the dominant physical feature on our planet Earth—covering approximately 70% of the planet's surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian and Arctic.

b. An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

c. Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of the Earth's rotation (Coriolis effect), and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation.

d. Sea level is the average height of the ocean relative to the land, taking into account the differences caused by tides. Sea level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.

e. Most of Earth's water (97%) is in the ocean and contains a constant proportion of dissolved salts (i.e. average salinity of 35). Seawater has unique properties: its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. The salt in the water comes from eroding land, volcanic emissions, reactions at the seafloor, and atmospheric deposition.

f. The ocean is an integral part of the water cycle and is connected to all of the earth's water reservoirs via evaporation and precipitation processes.

g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to coastal estuaries (where rivers meet the sea) and to the ocean.

h. Although the ocean is large, it is finite and resources are limited.

2) The ocean and life in the ocean shape the features of the Earth.

a. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.

c. Erosion—the wearing away of rock and soil—occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediments.

d. Most beach sand is carried to the coast by rivers and redistributed by waves and coastal currents. Erosion builds and destroys beaches. Winter storm waves carry sediments away from the beach and small summer waves carry sediments back onto the beaches.

e. Tectonic activity, sea level changes, and waves influence the physical structure and landforms of the coast.

3) The ocean is a major influence on weather and climate.

a. The ocean controls weather and climate by dominating the Earth's energy, water and carbon systems.

b. The ocean absorbs much of the solar radiation reaching Earth. The ocean releases heat by evaporation and this heat loss drives atmospheric circulation when heat released as water vapor condenses as rain. Condensation of water evaporated from warm seas provides the energy for hurricanes, cyclones and typhoons.

c. The El Niño Southern Oscillation causes the most important changes in global weather patterns because it changes the way heat is released to the atmosphere in the Pacific.

d. Most rain that falls on land originally evaporated from the tropical ocean.

e. The ocean dominates the Earth's carbon cycle. Half the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.

f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

g. Changes in the ocean's circulation have produced large, abrupt changes in climate during the last 50,000 years.

4) The ocean makes Earth habitable.

a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.

b. The ocean is the cradle of life—the first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

5) The ocean supports a great diversity of life and ecosystems.

a. Most life in the ocean exists as microbes, although ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.

b. Microbial organisms are the most important primary producers in the ocean. They not only are the most abundant life form in the ocean but also have growth rates that range from hours to days.

c. Most major groups of organisms (phyla) have many representatives living in the ocean.

d. Ocean biology provides many unique examples of important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer).

e. There are examples of life cycles in the ocean that are not often seen on land.

f. The ocean is three-dimensional, offering a lot of living space from the surface through the water column to the seafloor. As a result, most of the living space on Earth is in the ocean.

g. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substratum and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is “patchy”.

h. There are deep ocean ecosystems that rely only on chemical energy to support life (such as hydrothermal vents, methane cold seeps and whale falls).

i. Zonation patterns of organisms along the shore are influenced by tidal ranges and waves.

j. Coastal estuaries (where rivers meet the ocean) provide important and productive nursery areas for many marine species.

Appendix A

6) The ocean and humans are inextricably interconnected.

a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and almost all Earth's oxygen. It moderates the climate and influences our weather.

b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

c. The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is an important element of our cultural heritage.

d. Most of the world's population lives in coastal areas.

e. Humans affect the ocean in a variety of ways. Wastes (such as trash, sediments and sewage) enter the ocean from run off (non-point source pollution) and dumping (point source pollution). The pollution leads to habitat degradation, development of harmful algal blooms, and depletion of oxygen, as well as the endangerment, depletion, and extinction of ocean species. Coastal development, such as building structures along coasts and damming rivers leads to loss of beaches and increased coastal erosion. Through fishing, humans have removed most of the large vertebrates from the ocean, either directly or by harvesting their prey.

f. Coastal regions (where most people live) are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, typhoons, and storm surges).

g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

7) The ocean is largely unexplored.

a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes. Our very survival may hinge upon it.

c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential.

d. New technologies, sensors and tools are expanding our ability to explore the ocean. Oceanographers are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

e. Use of computer models is now an essential part of oceanography. They help us understand the complexity of the ocean and its interaction with Earth's climate. These models process observations and help describe the interactions among systems.

f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Appendix B
Detailed Analysis of Ocean Literacy Concepts in State Standards

Ocean Literacy

A chasm exists between modern scientific understanding about the role of the ocean in Earth system processes and current K-12 Earth science standards and curricula. On one side, recognition that the ocean is the dominant feature on Earth and that it plays a central role in Earth system processes is universally acknowledged within the Earth science research community. On the other side, within the K-12 education community, ocean specific education is largely absent or at best generalized in nature.

Recognition of the existence of this chasm prompted a diverse group of ocean scientists and educators to develop a strategic plan for improving ocean specific education across the K-12 grade span. A key initial step in this bridge-building effort was the development of a clearly articulated set of ocean literacy essential principles and fundamental concepts (Cava et al., 2005). These ocean literacy principles and concepts express the basic knowledge needed for an individual to be "ocean literate." They include seven "essential principles" of ocean literacy:

1. The Earth has one big ocean with many features.
2. The ocean and life in the ocean shape the features of the Earth.
3. The ocean is a major influence on weather and climate.
4. The ocean makes Earth habitable.
5. The ocean supports a great diversity of life and ecosystems.
6. The ocean and humans are inextricably interconnected.
7. The ocean is largely unexplored.

A detailed subset of supporting "fundamental concepts" underlies each these seven essential principles. Refer to Appendix A of this report for the entire set of ocean literacy essential principles and fundamental concepts.

While articulation and wide distribution of these ocean literacy principles and concepts has occurred, no systematic analysis has been conducted to determine the degree to which these ocean literacy concepts are already included within each state's science education standards. This study provides this information by examining how well each state addresses each of the ocean literacy fundamental concepts in their standards. In this study we reviewed every state's K-12 Earth science standards and identified all of the standard statements containing ocean literacy related concepts. Each standards statement was then analyzed to determine if it either directly or indirectly addressed any of the fundamental concepts of ocean literacy. Thirty-five of the forty-five fundamental ocean literacy concepts were correlated to state standards in this analysis. We did not analyze the ten fundamental concepts within essential principle number five, "The ocean supports a great diversity of life and ecosystems." This occurred because this analysis focused on Earth science standards, not biology standards, which are the primary conceptual area covered by essential principle number five.

Appendix B

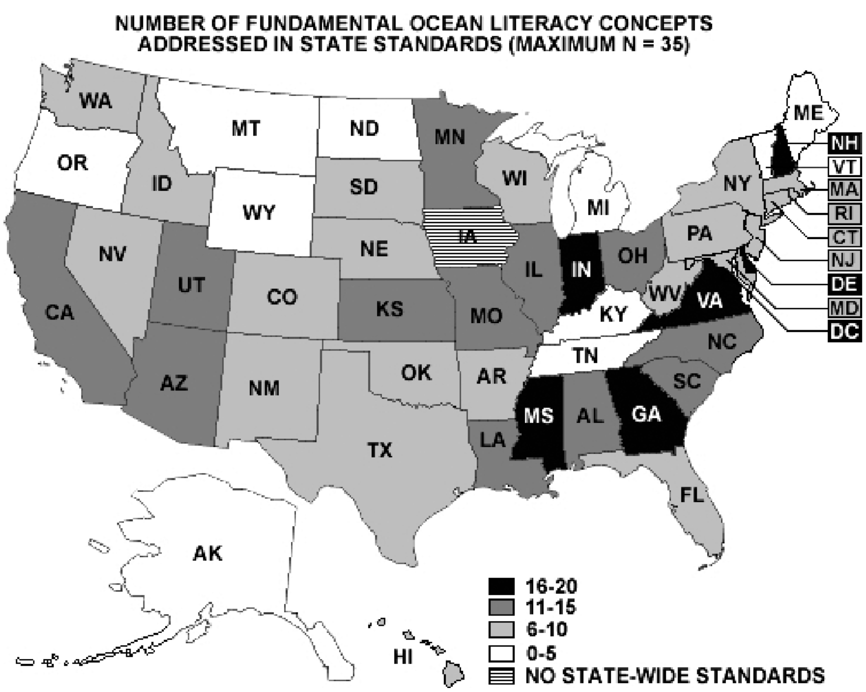
Ocean Literacy in State Standards

Across the nation, fundamental ocean literacy concepts are not commonly incorporated into state science standards. Forty-seven states, plus the District of Columbia, include at least a few ocean literacy concepts in their science standards, however, no state addresses more than twenty of the thirty-five fundamental ocean literacy concepts examined in this study. Thus, no state earns a grade higher than a "C." Three states—Iowa, Vermont, and Wyoming—do not address any of the ocean literacy concepts in their standards.

States that include the greatest number of ocean literacy concepts (16-20) within their standards are all located east of the Mississippi River. It is notable that each of these states is a coastal state. However, on average, the twenty-four coastal states (including the District of Columbia) address ocean literacy concepts only slight more frequently than the twenty-seven inland states (10.8 fundament concepts verses 8.5 respectively).

Figure B-1 below shows the number of fundamental ocean literacy concepts that are directly and indirectly addressed in each of the state's K-12 Earth and general science standards. This figure visually summarizes the more detailed, state specific data displayed in Table B-1.

Figure B-1: Total Number of Fundamental Ocean Literacy Concepts Directly and Indirectly Addressed in State Standards



State-by-state results of our analysis are summarized in Table B-1 below. This matrix indicates if a state's standards directly ("D"), indirectly ("I"), or fail (blank cell) to address each one of the thirty-five fundamental ocean literacy concepts reviewed in this study. The methodology for determining whether a standard statement directly or indirectly addresses a given fundamental concept is described in the Review Process and Criteria section of this report. Figure B-2, which is based upon the data presented in Table B-1, rank orders the states by the total number of ocean literacy concepts addressed in each state.

Table B-1: Coverage of Fundamental Ocean Literacy Concepts in State Science Standards

(Part 1—Continued on the following spread) (Refer to Appendix A of this report for the entire set of ocean literacy essential principles and fundamental concepts.)

OCEAN LITERACY ESSENTIAL PRINCIPLES			1. The Earth has one big ocean with many features.								2. The ocean and life in the ocean shape the features of the Earth.					3.The ocean is a major influence on weather and climate.						
FUNDAMENTAL CONCEPTS			1a	1b	1c	1d	1e	1f	1g	1h	2a	2b	2c	2d	2e	3a	3b	3c	3d	3e	3f	3g
STATE	# Fundamental Concepts Addressed [Maximum Possible=35, Mean=9.6]	# Fundamental Concepts Directly Addressed																				
Alabama	15	0		I	I		I	I				I	I	I	I	I	I	I	I	I	I	
Alaska	3	0			I			I	I													
Arizona	14	1	I		I		I	I	I				I	I	I	I	I		I	I	I	
Arkansas	8	0	I	I	I							I	I		I							
California	14	3	D	I	I	I	D	I	I		I				I	I	I	D	I		I	
Colorado	9	0	I	I	I		I	I	I						I	I					I	
Connecticut	9	1		I	I		D	I							I	I	I			I		
DC	17	9	D	I	I	I	I	D	D	I	I	D	D		D	D	D				I	
Delaware	18	1		I	I	I	I	I	I			I	I	I	I	D	I		I		I	
Florida	6	1	D					I					I	I	I	I						
Georgia	17	2	D	I	I		I	I	I		I		I	I	I	I	I		I		I	
Hawaii	6	0	I	I	I			I								I				I		
Idaho	6	0		I	I			I							I	I					I	
Illinois	15	0	I	I	I	I	I	I				I			I	I	I			I	I	
Indiana	16	4	D	I	D	I	I	I	I	I			I	I	I	D	I	I			D	
Iowa	0	0																				
Kansas	11	1			I		I	I					I	I		I	I				I	
Kentucky	4	0			I		I	I														
Louisiana	15	1	D	I	I			I	I		I		I	I	I	I	I			I	I	
Maine	4	0						I								I	I				I	
Maryland	8	0		I	I	I		I				I			I	I	I					
Massachusetts	6	2		I	I			D	I							I	D					
Michigan	5	0	I				I	I	I													
Minnesota	12	0	I	I	I			I			I		I	I	I	I	I			I		
Mississippi	20	3	I	I	I		I	I				I	I	D	I	D	I	I		I	D	
Missouri	15	0	I	I	I		I	I	I				I		I	I	I				I	
Montana	4	0		I				I								I	I					

Table B-1: Coverage of Fundamental Ocean Literacy Concepts in State Science Standards

(Part 1—Continued from the preceding page) (Refer to Appendix A of this report for the entire set of ocean literacy essential principles and fundamental concepts.)

OCEAN LITERACY ESSENTIAL PRINCIPLES			1. The Earth has one big ocean with many features.								2. The ocean and life in the ocean shape the features of the Earth.					3.The ocean is a major influence on weather and climate.						
FUNDAMENTAL CONCEPTS			1a	1b	1c	1d	1e	1f	1g	1h	2a	2b	2c	2d	2e	3a	3b	3c	3d	3e	3f	3g
STATE	# Fundamental Concepts Addressed [Maximum Possible=35, Mean=9.6]	# Fundamental Concepts Directly Addressed																				
Nebraska	6	0						I								I	I			I	I	
Nevada	10	0	I	I	I		I	I	I							I	I				I	
New Hampshire	17	3	D	I	I		D	I	D		I	I	I		I	I	I			I	I	
New Jersey	10	0	I		I		I	I	I						I	I				I	I	
New Mexico	6	1	I		I		D	I		I												
New York	7	1	D		I						I					I	I	I				
North Carolina	14	2	I		D		I		I			I	I	I		I	I					
North Dakota	5	0	I				I	I							I	I						
Ohio	15	2	D		I			I	I	I	I		I		I	I	I			I	I	
Oklahoma	7	1	D			I		I				I				I	I				I	
Oregon	3	0			I											I					I	
Pennsylvania	9	2	D	I	I		I		I						I	D	I				I	
Rhode Island	8	1	D	I	I			I							I	I	I				I	
South Carolina	13	4	I	I	I		D	I	I				D	D	I		I				I	
South Dakota	8	0	I	I	I			I							I					I		
Tennessee	5	0						I								I	I				I	
Texas	10	0	I	I	I		I	I	I							I	I			I	I	
Utah	14	0		I	I	I	I	I	I			I	I	I	I	I	I	I				
Vermont	0	0																				
Virginia	17	3		I	I	I	I	I	I			I	I	I	I	D	D				D	
Washington	9	4	I		D		D	I						I	I	D	I				D	
West Virginia	9	0		I	I	I	I									I	I				I	
Wisconsin	9	0	I	I	I			I							I	I				I	I	
Wyoming	0	0																				
# STATES ADDRESSING FUNDAMENTAL CONCEPT			31	30	40	10	28	42	22	4	8	12	19	15	30	41	34	6	5	15	31	0

KEY: D=Fundamental Concept Directly Addressed **I=Fundamental Concept Indirectly Addressed**

Table B-1: Coverage of Fundamental Ocean Literacy Concepts in State Science Standards

(Part 2—Continued on the next page)

	4. The ocean makes Earth habitable.		5. The ocean supports a great diversity of life and ecosystems. [Note: The essential principle was not analyzed in this study]										6. The ocean and humans are inextricably interconnected.							7. The ocean is largely unexplored.					
STATE	4a	4b	5a	5b	5c	5d	5e	5f	5g	5h	5i	5j	6a	6b	6c	6d	6e	6f	6g	7a	7b	7c	7d	7e	7f
Alabama																I						I			
Alaska																									
Arizona																						D			
Arkansas												I				I									
California																									
Colorado	I																								
Connecticut																I									
DC	D															I									
Delaware	I												I		I	I						D			
Florida																									
Georgia	D														I	I									
Hawaii																									
Idaho																									
Illinois	I												I			I						I			
Indiana																I									
Iowa																									
Kansas	D											I				I									
Kentucky	I																								
Louisiana	I															I									
Maine																									
Maryland																									
Massachusetts																									
Michigan																I									
Minnesota	I																								
Mississippi												I		I	I	I	I	I			I	I			
Missouri												I	I	I		I									
Montana																									

Table B-1: Coverage of Fundamental Ocean Literacy Concepts in State Science Standards

(Part 2—Continued from the previous page)

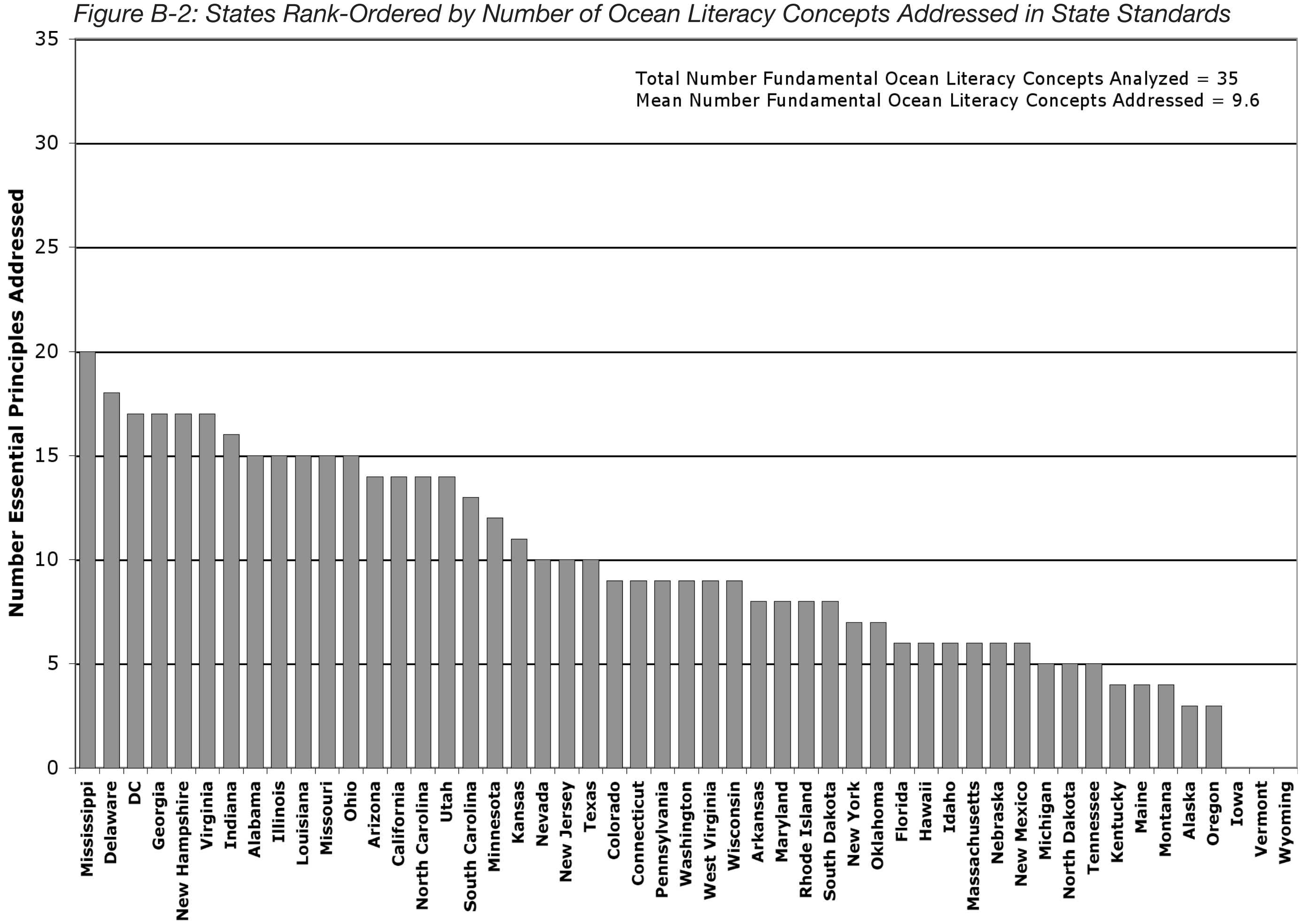
	4. The ocean makes Earth habitable.		5. The ocean supports a great diversity of life and ecosystems. [Note: The essential principle was not analyzed in this study]										6. The ocean and humans are inextricably interconnected.							7. The ocean is largely unexplored.					
STATE	4a	4b	5a	5b	5c	5d	5e	5f	5g	5h	5i	5j	6a	6b	6c	6d	6e	6f	6g	7a	7b	7c	7d	7e	7f
Nebraska	I																								
Nevada	I																								
New Hampshire	I	I														I									
New Jersey	I																								
New Mexico	I																								
New York	I																								
North Carolina												I	I	I	I	D						D			
North Dakota																									
Ohio	D															I									
Oklahoma																									
Oregon																									
Pennsylvania																									
Rhode Island																							D		
South Carolina	I															D									
South Dakota	I															I									
Tennessee																I									
Texas																									
Utah	I																								
Vermont																									
Virginia												I	I	I		I									
Washington																									
West Virginia	I															I									
Wisconsin	I																								
Wyoming																									
	21	1	0	0	0	0	0	0	0	0	0	0	6	5	4	4	21	1	1	0	0	1	6	1	0

Appendix B

The vast majority (89%) of the standard statements that address ocean literacy concepts do so indirectly with only 11% statements directly articulating the fundamental ocean literacy concepts. This is not an unexpected finding as it reflects the fact that most of the state's content standards were developed prior to the development of the ocean literacy essential principles and fundamental concepts that were first articulated in 2005 (Cava et al.).

The low number of standards directly corresponding to the ocean literacy concepts statements results from the fact the states have not historically placed a priority on ocean literacy and the fact that the ocean literacy standards were developed through a process that intentionally did not use existing state standards as a reference in the ocean literacy articulation process. It also is a reflection of the obvious fact that the ocean literacy concepts

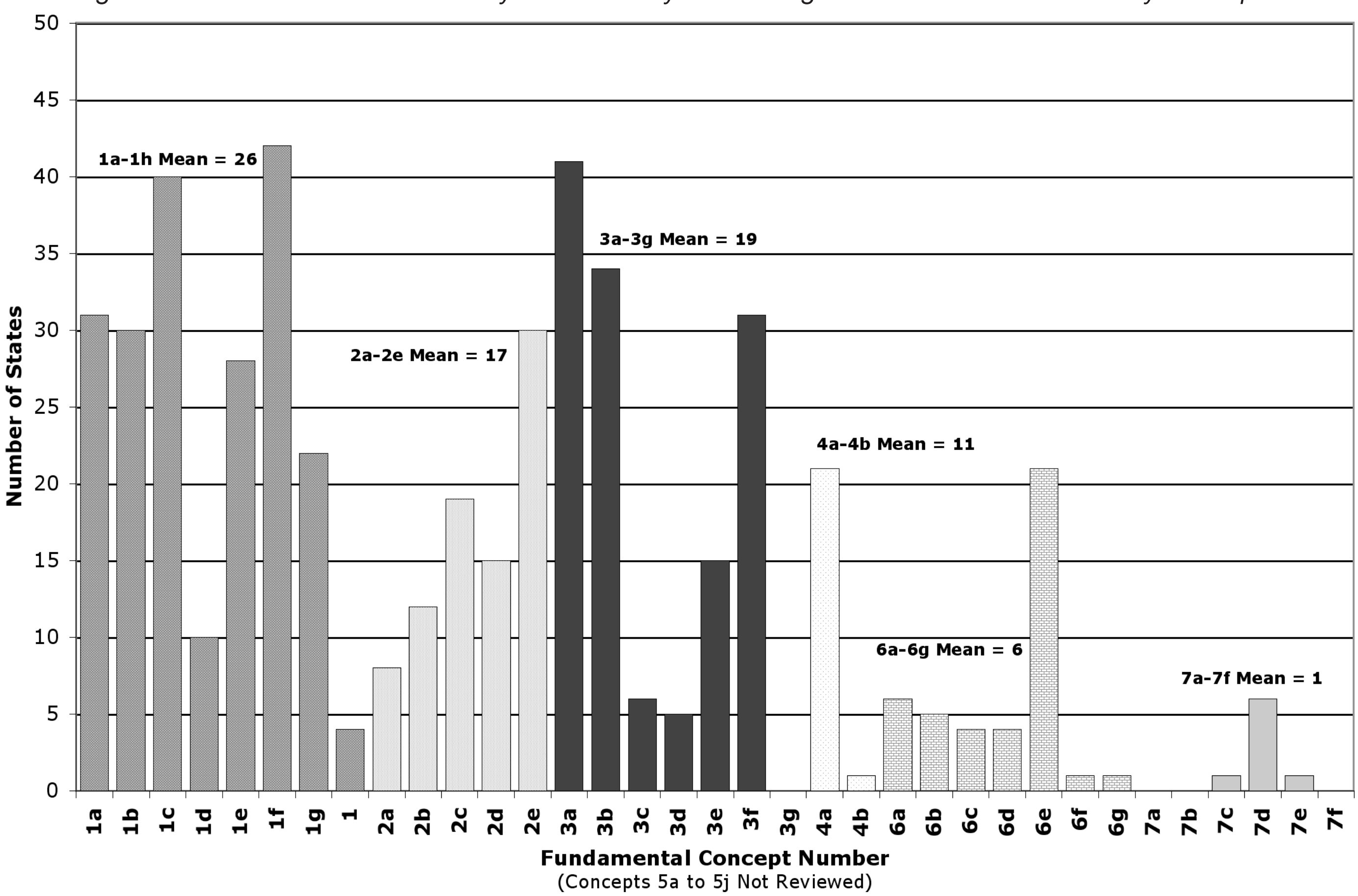
Figure B-2: States Rank-Ordered by Number of Ocean Literacy Concepts Addressed in State Standards



place the ocean at the center of all the conceptual statements, whereas the vast majority of existing Earth science content statements rarely specify or highlight the role of the ocean in Earth science content statements.

It is encouraging to note that twenty states, plus the District of Columbia, all of which have revised their state science standards since 2004, address more fundamental ocean literacy concepts, on average (10.7) than those states which have not recently revised standards (8.8). New Hampshire and the District of Columbia revised their science standards in 2006, thus making these standards the newest in the nation. Both of these states' standards do a better than average job at addressing ocean literacy concepts. Better inclusion of ocean literacy concepts in these new standards can be attributed to the availability of the Ocean Literacy: The Essential Principles and Fundamental Concepts of Ocean Sciences (Cava et al., 2005).

Figure B-3: Number of States Directly and Indirectly Addressing Fundamental Ocean Literacy Concepts



Appendix B

Essential ocean literacy principles that conceptually overlap with classically taught Earth science core concepts were more frequently addressed in state standards than the 2005 essential ocean literacy principles and fundamental concepts without that overlap. The number of states that address fundamental concepts 1, 2, and 3, which include significant conceptual overlap with classic existing Earth science content, are 26, 17, and 19 states respectively. See Figure B-3. In contrast, the number of states addressing fundamental concepts 4, 6, and 7, which do not strongly overlap with existing Earth science content, are only 11, 6, and 1 states respectively.

For example, most states have standards that cover concepts related to the water cycle, a classic Earth science concept that is also articulated in fundamental ocean concept number 1f, "The ocean is an integral part of the water cycle and is connected to all of the Earth's water reservoirs via evaporation and precipitation processes." Forty-two states at least indirectly address concept number 1f because it is a traditionally taught Earth science concept. On the other hand, fundamental concept 7a, "The ocean is the last and largest unexplored place on Earth…," is not a concept commonly included within the body of K-12 Earth science and is thus not addressed in any state standards. This dichotomy between classic Earth science content and the newly formulated ocean literacy concepts explains the finding that fewer states address ocean literacy concepts 4, 6, and 7.

Some state's science standards are generalized statements that can be interpreted to conceptually cover a broad set of ocean concepts. Even though such generalized content statements do not directly mention specific ocean concepts, many ocean concepts are implicitly contained within such statements. This is exemplified by the following fifth grade standard from Idaho; "Describe the interactions between the solid earth, oceans and atmosphere (erosion, climate, tectonics and continental drift)." Multiple ocean literacy concepts can be addressed with this statement, depending upon how it is interpreted. Another similar example is found in the Vermont standards; "Identify evidence of, model, and explain the patterns and forces that shape the earth (e.g., geological and meteorological processes)." This standard could include ocean-related processes, but does not specifically mention the ocean as an Earth-shaping force. Integrating ocean literacy concepts into those states that have chosen to articulate generalized content standards, rather than more conceptually discreet concepts, represents a significant challenge.

Appendix B

National Grade: D (GPA=1.0)

This grade represents a relatively simple, but familiar, format for reporting the overall degree to which ocean literacy principles and concepts are integrated into existing state standards across the nation. This national ocean literacy grade was calculated by assigning a letter grade to each state, according to the following grading scale, and then using a traditional four-point grading scale for the assigned letter grade to determine the national ocean literacy grade point average of all states plus the District of Columbia.

Number of Fundamental Concepts Directly or Indirectly Addressed in State Standards	Letter Grade
35-28	A
27-21	B
20-13	C
12-7	D
6-0	F

Ocean Literacy Recommendations

Our research shows that every state could improve its coverage of ocean literacy principles and concepts. Increasing the degree that ocean literacy concepts are incorporated into the fabric of general and Earth science teaching is a multi-faceted and long-term challenge. State and local standards need to be revised, teachers need to be better informed and trained, excellent curricular materials incorporating ocean literacy concepts need to be published, evidence needs to be gathered showing that students can learn essential core science content and scientific thinking skills when ocean literacy concepts are a central part of the curriculum, and lastly, state and national student assessments need to cover the domain of ocean literacy if teachers are to be expected to incorporate ocean literacy into their science teaching. As a whole, this is a daunting set of tasks to accomplish.

Since this study focused on state standards, we will center our recommendations on reforming state science standards. This involves systematic and direct involvement in the ongoing cycle of state standards revisions. Every state periodically revises its standards. Periods between revisions are commonly every four to six years, with some states having shorter or longer revision cycles. Each state's revision process provides a key opportunity for increasing coverage of ocean literacy.

Appendix B

Educators, educational researchers, research scientists, policy makers, and governmental agencies all need to participate in state standard revision processes if ocean literacy is to gain a foothold in the revised standards. Maximum effect will probably occur if all of these players become involved with the state education agencies responsible for standards revisions early in the revision process by making responsible individuals and entities aware of ocean literacy principles and their relationship to specific content and thinking skills. The ocean literacy community must show that ocean literacy is comprehensive in nature and that inclusion of ocean literacy principles will not necessarily require elimination of other key science concepts.

Revising state content standards that already indirectly address ocean literacy concepts so they more specifically incorporate the role of the ocean in Earth system processes probably represents the best opportunity for improving the coverage of ocean literacy concepts across Earth science curricula. Incorporating ocean literacy concepts that are not directly related to existing Earth science content will be a much greater challenge. Successful incorporation of ocean literacy standards will necessitate clearly demonstrating how ocean literacy concepts are essential core principles that provide a context for exemplary Earth system science teaching and learning.

Efforts to increase ocean-related education in the K-12 arena should not center entirely on improving or changing standards. While standards serve as a guide for teachers regarding the skills and knowledge they should teach their students, they do not specify exactly how a teacher should go about teaching. Teachers should thus be considered to be another key avenue through which ocean literacy education can be expanded. Teachers must be provided with the professional knowledge and skills, as well as curricular resources, to better integrate ocean literacy education into their teaching. Therefore, the ocean literacy and Earth system science education community should pursue a two-pronged approach that simultaneously focuses on revising state standards, when opportune, while simultaneously taking steps to making teachers aware of the importance of including ocean literacy principles.

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