Developing and Applying a Set of Earth Science Literacy Principles

Michael E. Wysession,[1,a] Nicole LaDue,[2] David A. Budd,[3] Karen Campbell,[4] Martha Conklin,[5] Ellen Kappel,[6] Gary Lewis,[7] Robert Raynolds,[8] Robert W. Ridky,[9] Robert M. Ross,[10] John Taber,[11] Barbara Tewksbury,[12] and Peter Tuddenham[13]

ABSTRACT

The 21st century will be defined by challenges such as understanding and preparing for climate change and ensuring the availability of resources such as water and energy, which are issues deeply rooted in Earth science. Understanding Earth science concepts is critical for humanity to successfully respond to these challenges and thrive in the decades to come. As part of efforts to address this, a new program called the Earth Science Literacy Initiative (ESLI) was formed in 2008 with funding from the National Science Foundation (NSF). Its task was to create a succinct document outlining what citizens should know about Earth science. This document, called the Earth Science Literacy Principles (ESLPs), has applications in both public and private arenas. For example, the ESLPs have been used to define the core ideas of both a middle school textbook program and a new set of K–12 science education standards. The ESLPs, which are founded in a broad representation of the geoscience community, based upon current research, and endorsed by major government, industry, and academic geoscience organizations, represent an effort by the Earth science community to create a coherent and fundamental set of big ideas and supporting concepts that represent our fields. [DOI: 10.5408/11-248.1]

Key words: Earth science, fundamental principles, literacy, standards, public policy

INTRODUCTION

Given the importance and societal relevance of many areas of Earth science, there has been growing recognition that the geoscience research community needs to do a better job of communicating its findings and discoveries to the public. For example, in a *Science* editorial, Norman Augustine, chairman of the committee that produced "The Gathering Storm" report, reprimanded American scientists for being apathetic, uninvolved, and disconnected from modern society and politics [Augustine, 2008]. As he put it, "the 'scilence' is deafening." This is particularly relevant for Earth scientists. There are many significant societal challenges involving natural resources, natural disasters, and human impacts on Earth systems, but few Americans receive formal high school education in the geosciences. So of all the sciences, Earth science literacy is particularly low.

Several factors make increasing Earth science literacy important. There is a current awareness that global financial health depends upon access to reliable and safe energy sources, most of which are associated to some degree with Earth science. Water, soil, and mineral resources are becoming critically scarce in some areas, exacerbated by increases in human population and global industrialization. The reality of global climate change is widely accepted, but many questions remain as to its consequences in terms of sea level rise, droughts, forest fires, desertification, and storm intensification. In addition, the impacts of human activities are increasingly affecting climate, land erosion, water and air quality, and the health of the biosphere. Increased Earth science literacy will help policymakers and voters make informed decisions about these critical issues.

SCOPE AND CONTEXT

The ESLPs clearly and concisely define the important and essential information of Earth science. While "Earth science" means different things in different contexts, the ESLI organizing committee set a limitation on the scope of its literacy initiative to include those aspects of geology and land-based hydrology that are funded within the Earth science program of the National Science Foundation (NSF-EAR), which includes geobiology and low-temperature geochemistry, geomorphology and land-use dynamics, geophysics, hydrologic sciences, petrology and geochemistry, sedimentary geology and paleobiology, and tectonics. This was largely done to avoid overlap with literacy initiatives associated with the ocean, atmosphere, and climate. These other literacy initiatives preceded the current

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[1]Washington University, St. Louis, Missouri 63130, USA
[2]Michigan State University, Geological Sciences, East Lansing, Michigan 48824, USA
[3]Department of Geological Sciences, University of Colorado at Boulder, Boulder, Colorado 80309, USA
[4]National Center for Earth-Surface Dynamics, University of Minnesota, Minneapolis, Minnesota 55414, USA
[5]School of Engineering, University of California–Merced, Merced, California 95343, USA
[6]Geo Prose, 5610 Gloster Road, Bethesda, Maryland 20816-2058, USA
[7]Geological Society of America, Boulder, Colorado 80301, USA
[8]Denver Museum of Nature and Science, 2001 Colorado Boulevard, Denver, Colorado 80205, USA
[9]United States Geological Survey, 12201 Sunrise Valley Drive, Reston, Virginia 20192, USA
[10]Paleontological Research Institution Outreach, 1259 Trumansburg Road, Ithaca, New York 14850, USA
[11]Incorporated Research Institutions for Seismology, 1200 New York Avenue NW, Suite 800, Washington, DC 20005, USA
[12]Department of Geosciences, Hamilton College, Clinton, New York 13323, USA
[13]College of Exploration, 230 Markwood Drive, Potomac Falls, Virginia 20165, USA
[a]Author to whom correspondence should be addressed. Electronic mail: michael@wucore.wustl.edu.

effort and served as direct models for the current ESLI project:

- "Ocean Literacy: The Essential Principles of Ocean Sciences, K–12" [Ocean Literacy Network, 2005]
- "Atmospheric Science Literacy: Essential Principles and Fundamental Concepts of Atmospheric Science" [Atmospheric Science Literacy Framework, 2007].
- "Climate Literacy: The Essential Principles of Climate Sciences" [U.S. Climate Change Science Program, 2009]

Although these separate literacy efforts focus on different content areas, they have similar goals and have been developing cooperatively and parallel to one another and ESLI. This cooperation is fostered by organizations such as the Coalition for Earth System Education, an affiliation of organizations that seek Earth science parity with other sciences and Earth science literacy enhancement. Discussions have begun to create a broader "Earth system science" literacy framework containing content from all areas of geoscience, which will further unify the geoscience community in conveying the fundamentals of our science with a single voice.

ESLI PROCESS

ESLI began the development of the ESLPs during early 2008. For this document to represent the current understandings of Earth science, the various Earth science communities included in the scope of the project had to have multiple opportunities to participate in its construction and review. This process included an online workshop, an in-person workshop, and an extended period of peer review.

ESLI began with a core of a dozen organizing committee members, at the invitation of NSF program officers, who represented an array of Earth science disciplines, as well a wide scope of professional activities that included research, formal K–12 and university education, informal education, government, and professional societies. The organizing committee solicited participation from Earth scientists via email and Web site postings associated with the major professional societies, government labs, and universities, spanning the NSF-EAR research fields. About 350 Earth scientists and educators volunteered to collaborate on the project, and in May 2008, the organizing committee ran a 2-week online workshop for these people. The workshop was hosted, in cyberspace, by the College of Exploration.

The online workshop was successful in gathering information from a large number of Earth scientists and educators in an efficient and affordable (and with minimal carbon impact) manner. By the end of the 2-week workshop, the participants had converged upon a set of Earth science "big ideas," as well as a great deal of supporting documentation.

A synthesis of the online workshop content provided the foundation for an in-person 3-day writing workshop involving a group of 36 people that largely consisted of the organizing committee and invited participants from the online workshop. This workshop produced a draft framework of the big ideas and supporting concepts that was edited by the organizing committee and presented to the public at the Geological Society of America meeting in October 2008. This was followed by a subsequent period of open online review and revision by independent reviewers. The revised document was then presented at the fall meeting of the American Geophysical Union in December 2008, followed by another period of open online independent review and revision. A near-final draft was assembled during February–May 2009, with layout and graphics text reviewed by the company Geo Prose. This draft went to government and professional organizations for review and endorsement. In total, more than 700 people were involved in the formation of the ESLPs, with all comments documented in an online archive. The big ideas and supporting concepts were aligned with National Science Education Standards (NSES) [National Research Council, 1996; ESLI, 2009]. More details about the construction of the document, as well as plain-text and graphic versions of the document, can be found on the ESLI Web site.

The ESLPs went through extensive formative assessment, both internally and externally. In addition to open online review, they were circulated among several organizations for evaluation before publication. An important component of the validity of the ESLPs is their endorsement by major governmental, industrial, and academic geoscience organizations, such as the American Association of Petroleum Geologists, American Geosciences Institute (AGI), American Geophysical Union, Geological Society of America, National Association of Geoscience Teachers, National Earth Science Teachers Association, Smithsonian Institution, and U.S. Geological Survey. To increase its audience, the ESLPs have been translated into Spanish and are in the process of being translated into French.

THE BIG IDEAS OF EARTH SCIENCE

It was a challenging task to reduce the understandings of a vast field of study to a small number of short sentences. Nine big ideas resulted from the iterative, community-based efforts of the workshops and online reviews. When the online workshop began, participating geoscientists quickly identified a small number of major content-based themes as being fundamental to our science (big ideas 2–6; Table I). As conversations developed and focused on the purpose of the document, the participants felt it was important to put the process of science as the first big idea, because basic science literacy is often an obstacle for people attempting to understand the content of science. The writers and reviewers recognized the need to make the ESLPs relevant to the lives of the people who would be reading it, so three big ideas (7–9) focused on humans and their interactions with Earth.

While these big ideas were determined independently from other literacy efforts, they bear similarities to other endeavors. For example, the influential "Basic Research Opportunities in Earth Sciences" report [National Research Council, 2001] listed five main societal challenges for Earth science: (1) discovery, use, and conservation of natural resources; (2) characterization and mitigation of natural hazards; (3) stewardship of the environment; (4) geotechnical support for commercial and infrastructure development; and (5) terrestrial surveillance for global security and national defense. These and other key ideas are fully represented among the ESLPs we have constructed here.

DISSEMINATION AND APPLICATIONS OF THE ESLPS

The completion of the ESLPs also marks the beginning of another, and in many ways more significant, project: the dissemination of the ESLPs for use across a range of important areas. Just as with scientific research, it is not enough to simply publish a literacy document; the message needs to be carried to the public. ESLI is taking several steps to ensure these big ideas enter the numerous arenas for which they were intended, but the entire Earth science community needs to increase its outreach activities. To help facilitate this, the ESLPs are available through several channels: a Web site, brochure, and videos. The Web site (www.earthscienceliteracy.org) contains the ESLPs in document and portable document formats in both English and Spanish. It also contains information about the ESLI process. The ESLPs were published in the form of a color brochure and converted by the AGI a set of animated video segments available on the ESLI Web site. With the help of professional organizations, universities, and industry, the ideas of the ESLPs, in their different formats, are reaching schools, boardrooms, legislative halls, museums, textbooks, and a large number of citizens.

A major route for dissemination of the ESLPs has been in the area of formal education. More than 16,000 copies of the brochure for the ESLPs were sent to K–12 Earth science teachers as part of packets distributed to schools by the AGI during Earth Science Week, October 11–17, 2009. Individual K–12 and university science teachers and supervisors have continued to request bulk copies of the brochure for the ESLPs for distribution to their students, and this availability continues (contact: michael@seismo.wustl.edu). The digital video versions of the ESLPs provide a means of disseminating the big ideas in a format that is easily used in classroom settings, allowing a group of students to share in viewing and discussing the concepts. More than 15,000 DVDs of the AGI video documentary of the ESLPs were sent out as part of Earth Science Week packets in October 2011.

Direct dissemination has also been important for informal education institutions such as science centers and state and national parks, which have distributed thousands of copies of the brochure for the ESLPs. Projects related to Earth science curriculum development funded under the NSF Education and Human Resources program will need to align their content with the ESLI framework. A recent project funded through the NSF Science, Technology, Engineering, and Math Talent Expansion Program initiative called InTeGrate (or Interdisciplinary Teaching of Geoscience for a Sustainable Future) uses the ESLPs to guide curriculum development. A request for proposals by the Corporation for Public Broadcasting to create video products relating to climate change is requiring alignment to the ESLPs for all proposals. Many congressional staff members working with representatives in the U.S. House and Senate have also been briefed on the ESLPs. This was particularly relevant for Congress members on committees related to or involved with the funding of science.

Science literacy frameworks are important for guiding the content development of new science textbooks. In the past, textbooks were vital for providing access to *basic* information such as facts and details, because this information was not easily accessible elsewhere. With the digital information explosion, which allows real-time access to vast amounts of factual information via the Internet, textbooks are now needed to provide a different role. They can present to students the *essential* information that is a small subset of the total information available but that represents what is most important for the students to learn. However, textbook writers and editors face the same challenge that teachers face: how to select the most relevant and important scientific information [e.g., Wysession et al., 2004]. As an example, the ESLPs were used to guide the formation of a new K–8 national science program by Pearson Prentice Hall [Padilla et al., 2010, 2011]. The big ideas in the ESLPs inspired a parallel set of big ideas in Earth science that guided the generation of the structuring of the content for the program.

To facilitate the use of the ESLPs in formal education materials, each supporting concept was aligned to NSES [ESLI, 2009]. Current research, as highlighted in "Taking Science to School" [National Research Council, 2007] and "Ready, Set, Science" [National Research Council, 2008], has found that scientific reasoning is best taught through a connection between scientific practices and scientific content. In addition, educational reforms are increasingly using big ideas and theme-based curricula to provide a deeper understanding of science. Curriculum development tools such as "Earth Science By Design" [TERC and AGI, 2012], modeled after the *Understanding by Design* technique [Wiggins and McTighe, 2005], employ a backward design that starts with big ideas as a basis for K–12 curricular choices. The ESLPs can provide the basis for this kind of curricular development.

However, the greatest impact of the ESLPs has probably been in guiding the Earth science content of a new set of NSES. In 2011, the National Academy of Sciences released "A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas" [National Research Council, 2011], which incorporated current research in both science and science education. This framework laid the groundwork for the construction of a set of science standards that weaves together science concepts, crosscutting science ideas, and scientific practices. The ESLPs provided the foundation for the Earth science content through the work of an independent Earth and Space Science Design Team. The work in writing the "Next Generation Science Standards" by the organization Achieve began in 2011 with the release of the National Research Council framework. The ESLPs continue to guide the writing of the standards, which are planned for release in 2012.

It is important to assess the impact of introducing the ESLPs into both formal and informal educational settings. These assessments should involve social scientists, as well as informal and formal evaluation experts. A broad assessment of the public understanding of the ESLPs may be conducted by large social science research projects, such as the recently released report "Global Warming's Six Americas" [Maibach et al., 2009], which captured the current attitudes about global warming through a survey. One important direction would be to see how the ESLPs address and correct misconceptions that students have about Earth and its systems. In the formal K–12 system, a captive audience can be assessed using standardized tests, even though these assessments often fall short in assessing robust scientific conceptual frameworks. In informal education, we can call upon resources such as the recent "Learning Science in Informal Environments" report [National Research Council,

TABLE I: The nine big ideas of the ESLPs.

No.	Big Idea	Description
1	Earth scientists use repeatable observations and testable ideas to understand and explain our planet.	Science is an ongoing process of discovery, and Earth science is part of this process. Science draws upon the innate sense of curiosity that all humans share. Earth scientists formally pursue the process of discovery by making observations, testing hypotheses, and refining models of Earth. The power of the scientific process is evident from our continual march toward better explanations of how the laws of the universe shape our planet.
2	Earth is 4.6 billion years old.	The big debate over Earth's age, such an exciting geologic topic of past centuries, is over. We are now working on the third or fourth significant digit. Earth has a long history, and geologists have already figured a great deal of it out. Primarily through radioactivity, but also through many other creative means of dating the ages of rocks and ice, geologists have pieced together a fascinating history for the rocks, ocean, atmosphere, and living organisms of this planet.
3	Earth is a complex system of interacting rock, water, air, and life.	All parts and processes of Earth are interconnected. Changes in one part of Earth's systems cause changes in other systems, often in unpredictable and irreversible ways. Energy constantly flows and mass cycles within and between these Earth systems.
4	Earth is continuously changing.	Our whole planet is in motion, at all levels. Some change occurs slowly, such as building mountains and moving continents. Some change occurs suddenly, through catastrophic volcanic eruptions and devastating earthquakes. In keeping with the document's focus, the supporting concepts of this big idea highlight change in the geosphere and continental hydrosphere.
5	Earth is the water planet.	The presence of water in all three phases (solid, liquid, and vapor) uniquely controls much of the way Earth works. Water is not only the foundation of life but also controls much of the geochemistry and the physical behavior of Earth materials. The cycling of water through Earth's different systems is largely responsible for the appearance of Earth's surface.
6	Life evolves on a dynamic Earth and continuously modifies Earth.	The biosphere plays a vital role in shaping Earth's outer layers. In return, the course of biologic evolution has been shaped by the natural selection of organisms in changing environments. Organisms, especially unicellular, have become adapted to virtually every nook and cranny of Earth. The chemistry of the atmosphere, ocean, and surface geosphere is dominated by biologic activity. Millions of years of biologic activity are behind the vast buried energy stored in "fossil" fuels.
7	Humans depend upon Earth for resources.	Earth is our home; we depend upon it for our subsistence. The availability of natural resources has determined where cities and civilizations have arisen. The supplies of many resources—water, soil, minerals and metals, and fossil fuels—are unevenly distributed and globally limited and have long been a source of political and social turmoil.
8	Natural hazards pose risks to humans.	Many natural Earth science–related processes are extremely destructive to life and property, and the natural history of severe geologic events has shaped the course of human history. Though we cannot stop these hazards, we can attempt to determine when and where they might occur, reduce activities that exacerbate their impacts, and take actions to reduce the likelihood of some hazard types.
9	Humans significantly alter Earth.	Human activities now cause environmental changes in many areas at a rate faster than that of any other geologic process, significantly altering the atmosphere, ocean, biosphere, climate, and land surface. Increases in both human populations and levels of industrialization are causing a rapid rise in the magnitude of human impacts on Earth.

2009] to identify methods of assessing gains in Earth science literacy. Here, focus groups, questionnaires, audio and visual recordings, and interviews, specifically involving the "think-alouds" technique, are appropriate approaches for assessing scientific literacy gains following incorporation of the ESLPs. While these assessment mechanisms are important, no funding is available to carry them out, and we know of no such assessments under way.

The exercise of creating a single document of Earth science knowledge that is endorsed by multiple representatives of the geoscience research, government, and professional communities is both rewarding and reassuring to Earth scientists. The body of Earth science content is like an ever-expanding sphere of understanding. Earth science research community members spend most of their time at the outer edge of this sphere, constantly trying to grow the sphere by changing the unknown into the known. This is an uncertain and contentious world, filled with false leads, wrong turns, argument, and debate. To observers, it may look like our world is dominated by disagreement and confusion. But the document presented here is a reminder that inside this surface of discovery is a deep, rich, and spectacular body of knowledge about our planet. It is our responsibility as geoscientists to make sure that others get to share in this understanding.

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