

# Educator Perspectives on Earth System Science Literacy: Challenges and Priorities

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## ABSTRACT

The challenges and priorities of defining and achieving Earth System Science (ESS) literacy are examined through surveys of geoscience educators attending a professional geological meeting. Two surveys with Likert-style and free-response questions were distributed to geoscientists and K–12 teachers to elicit what instructors think are important concepts, experiences, and hurdles to ESS literacy. Survey 1 asked participants open-ended questions about the challenges and priorities of ESS literacy. Survey 2 asked participants to evaluate the importance of various concepts for nonscience majors taking an ESS course. Survey 1 results indicate that the geoscience professors and K–12 teachers place emphasis on the relevance of Earth Science for public decision-making and regard formal education as having an important role in building Earth Science literacy. Respondents identified weaknesses of K–12 ESS education and the lack of respect for the geosciences as substantial hurdles for ESS literacy. Survey 2 results reveal that respondents highly value integrated Earth Systems concepts, such as, Earth systems involve complex interactions between rock, water, air, and life. Less value is placed on fact-like statements that cover a narrow range of content, such as the age of the Earth and that Earth is mostly covered by an ocean. Results from both surveys indicate that K–12 teachers value teaching the interconnectedness of humanity and the Earth more so than do professors. This study identifies geoscience educators' perspectives of Earth Systems Science Principles and reveals the need for a more cohesive movement to promote the importance of ESS and develop ESS literacy in the general public. © 2012 National Association of Geoscience Teachers. [DOI: 10.5408/11-253.1]

**Key words:** Earth system science literacy, K–12 education, geoscience challenges, essential principles

## INTRODUCTION

In 2009, the Organisation for Economic Co-operation and Development (OECD) reported that U.S. K–12 students perform below average on environmental science and geoscience questions relative to many other nations. The United States performed worse than 48 of the 57 countries participating in the 2006 Program for International Student Assessment (PISA; OECD, 2009). Not surprisingly, very few states emphasize Earth System Science (ESS) content in college preparatory, high school courses (American Geological Institute, 2008), suggesting that the U.S. K–12 system is failing to teach important Earth and environmental science content.

The lack of emphasis on ESS education in the U.S. is being addressed on a multiple fronts. The recently released Framework for K–12 Science Education, which is being used to define new national K–12 science education standards, includes a substantial Earth Science component (National Research Council, 2011). Federal agencies have supported several initiatives to focus the geoscience education community around the most important concepts governing the Earth sciences (Wysession et al., 2012). Oceanographers, climatologists, atmospheric scientists, and Earth scientists have defined four sets of essential principles (also known as “big ideas”) of ESS concepts (Atmospheric Science Literacy, 2008; Earth Science Literacy Initiative, 2009; National Geographic

Society et al., 2005; U.S. Global Change Research Program—Climate Change Science Program, 2009). These four documents were developed through extensive community consensus processes governed by panels of expert geoscientists. The principles outlined in the literacy documents provide a high quality catalog of important Earth Science topics. However, when the principles from the four Earth Science domains are viewed as a single, combined list, the total number of principles is 31. These attempts have been heroic in terms of uniting and generating consensus among concerned scientists. However, as Ross and Duggan-Haas (2010, p. 27) pointed out, “no examples of creating a thick description of what everyone should understand about every topic have led to wide swaths of the population understanding the target content.” Many of these 31 principles have overlapping relevance across the four domains, and so a shorter, integrated list is needed to promote ESS literacy.

In the context of a national inadequacy in ESS education and an overabundance of important Earth-relevant principles, we ask two questions: (1) What do geoscience faculty and K–12 Earth Science teachers see as the challenges and priorities for achieving ESS literacy? and (2) What are the most important topics to cover in an undergraduate Earth Science course that is intended for nonscience majors? To address our research questions, we solicited input from K–12 Earth Science teachers and university geoscience professors who were attendees to a geoscience conference. The responses to our survey questions can contribute to the discussion of what geoscience educators think it means to be ESS literate.

## LOCATING THE RESEARCHER

In studies involving interpretation of data that is, fundamentally, participants' thoughts on a topic, the

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researchers may be viewed as a research instrument. As with any instrument they have internal biases that need to be acknowledged (Feig, 2011; Maxwell, 2005; Patton, 2002). Here we present a brief background of the researchers to provide the reader with context for our interest in undertaking this study and the influence of our experiences on the study design and data interpretation. The researchers include a former New York State high school Earth Science teacher, currently pursuing a PhD in geological sciences, and an Assistant Professor of Geology. The former was involved in the development of the Earth Science Literacy Principles (Earth Science Literacy Initiative, 2009; Wyssession et al., 2012) and has the primary discourse of a classroom teacher. The latter has experience with the K–12 system through a National Science Foundation GK–12 fellowship and has a primary discourse of a scientist. The combination of these two perspectives aims to offer a balanced viewpoint for interpretation of K–12 teachers' and geoscientists' qualitative responses in the surveys examined in this paper.

## METHODS

Geoscience professors and K–12 Earth Science teachers attending the 2009 Annual Meeting of the Geological Society of America were recruited at a booth in the exhibit hall and received a candy bar in exchange for their participation in one of the two 15-minute surveys. The two surveys were designed to elicit the participants' perceptions of challenges and priorities for public ESS literacy (Survey 1) and the relative importance of various ESS concepts for undergraduate nonmajor courses (Survey 2). The surveys included a Geoscience Experience Questionnaire (GEQ) to evaluate geoscience experience and collect demographic data (Appendix A). This version of the GEQ is modified from a general measure of experience developed by the Michigan State University Geocognition Research Laboratory. The GEQ scoring discriminates between geoscience expert (scoring over 10 points), beginning professional (scoring between 5 and 10 points), and novice (scoring under 5 points). The GEQ was given at the end of the survey so that a stereotype effect did not interfere with the participants' responses (Steele and Aronson, 1995; Shih et al., 1999).

### Survey 1

For Survey 1, 11 K–12 teachers and 25 geoscience professors were asked six free-response questions to uncover their perspective of ESS literacy for the general public (Appendix B). Questions 4, 5, and 6 provide insight regarding participants' perspectives on the role of Earth Science in science literacy, important experiences for building ESS literacy, and substantial hurdles to ESS literacy, respectively. Questions 1 and 2 are not specifically related to our current research questions, and responses to question 3 indicated the question did not have face validity in that participants did not interpret the question as it was intended by the researchers.

The authors and a trained undergraduate researcher coded Survey 1 using a thematic content analysis (Denzin and Lincoln, 1998; Patton, 2002). All responses were coded as one data set and the responses were categorized by common themes. The themes identified by the first author were explained to the undergraduate researcher, and they practiced categorizing several participant responses to establish criteria

for coding responses into specific categories. Subsequent to the training, the first author and undergraduate researcher independently coded all of the responses for questions 4 and 5. Comparison of the codes assigned by each rater provides a measure of interrater reliability. We report this reliability using kappa, where kappa values of 0.610–0.80 indicate a substantial agreement between raters' codings, and values  $>0.80$  represent an almost perfect agreement between raters' codings (Landis and Koch, 1977). The interrater reliability for coding of question 4, "What role does Earth Science play in creating a scientifically literate public?" had a kappa of 0.74 ( $p < 0.001$ ). The kappa for question 5, "Which experiences are most important for building Earth Science literacy?" was 0.64 ( $p < 0.001$ ). Where necessary, new categories were created for responses that both researchers agreed did not fit into the original set of categories. The first author and undergraduate researcher reached complete agreement on the placement of the remaining responses. Both authors coded question 6, "Describe the THREE biggest hurdles facing the geoscience education community in promoting Earth Science literacy for all people," according to a similar protocol, however the complexity of responses required an additional step of coding. The second author coded responses independently according to the categories defined by the first author. Together, they redefined the thematic group boundaries and added subcategories as appropriate. Many responses were coded into more than one of the subcategories. The authors then recoded question 6 using the agreed upon revised framework and achieved a kappa of 0.79 ( $p < 0.001$ ). Subsequently, the authors discussed and agreed upon the recategorization of the 10 responses that were categorized differently.

The coding process for Survey 1 required defining specific boundaries for categories. For example, in coding question 4, two themes emerged that were similar. Many responses included reference to the human–Earth connection in general terms and many other responses included specific tangible Earth resources, hazards or specifically mentioned decision-making. Therefore, two categories were created: The Human–Earth Environment and Informed Public/Decision-Making. A response such as: "Extremely important to understand the world we live in and our relationship with the environment." (Participant 26-S) would be coded in the former category, while a response such as: "[Earth Science] is part of almost every election ballot, i.e., air, water land use, open space, etc." (Participant 13-T) was coded into the latter category. While both categories relate to humanity's relationship with Earth, the Informed Public/Decision-Making responses are more pointedly focused on a specific functional goal of science literacy. Several responses for questions 4 and 5 were coded into more than one category where themes crosscut multiple categories. Question 6 asks for the "three biggest hurdles"; therefore, the answers were separated into three responses for each participant and very few of these responses required coding into more than one category. The coded data for Survey 1 is available at: <http://dx.doi.org/10.5408/11-253s1>.

### Survey 2

Survey 2 was designed to gauge the importance placed on 11 concepts as learning goals for nonscience majors enrolled in undergraduate ESS courses (Appendix C). The list of content goals was generated by integrating the essential principles published by four distinct Earth Science

TABLE I: Earth System Science Essential Principles (ESSEPs). The 11 concepts below crosscut the Atmospheric Science, Climate, Earth Science, and Ocean Literacy documents. The numbers correlate to the essential principles/big ideas as listed in the original documents.

Earth System Science Essential Principles	Atmospheric Science <sup>1</sup>	Climate	Earth Science Literacy	Ocean
1. Exploration of Earth systems occurs through observations, scientific reasoning, and modeling.	6	5	1	7
2. Earth systems involve complex interactions between rock, water, air, and life.	5	2	3	3
3. The Sun is the primary source of energy for Earth's climate system.	2	1		
4. Matter and energy are transported and transformed by Earth system processes (e.g., tectonic plate motions, denudation, and atmospheric and oceanic circulations).	3			
5. Earth systems are continuously changing.	4	4	4	
6. Humans are inextricably interconnected to the geosphere, hydrosphere, and atmosphere.	7		7	6
7. Natural disasters and climate change threaten human civilization.		7	8	
8. Humans have become a significant agent of change to the geosphere, hydrosphere, and atmosphere.		6, GP <sup>2</sup>	9	
9. The biosphere depends on and affects the hydrosphere, the atmosphere, and the geosphere.	1	3	6	2, 4, 5
10. Earth has a multifaceted ocean that covers most of Earth's surface.			5	1
11. Earth is 4.6 billion years old.			2	

<sup>1</sup>The literacy guides may be found online at: Atmospheric Science Literacy, <http://eo.ucar.edu/asl/>; Climate Literacy, <http://cleanet.org/cln/>; Earth Science Literacy, <http://www.earthscienceliteracy.org/>; Ocean Literacy, <http://oceanliteracy.wp2.coexploration.org/>.

<sup>2</sup>The Climate Literacy guide includes a "Guiding Principle" denoted here as GP.

communities into one concise list of common principles (Atmospheric Science Literacy, 2008; Earth Science Literacy Initiative, 2009; National Geographic Society et al., 2005; U.S. Global Change Research Program—Climate Change Science Program, 2009). Integration of the principles was accomplished using a thematic content analysis of the four documents (Table I). Where similarities exist between domain concepts, an Earth System Science Essential Principle (ESSEP) was written to capture the essence of the individual concepts. For example, the ESSEP: *Exploration of Earth Systems occurs through observations, scientific reasoning, and modeling* is a synthesis of:

- *We seek to understand the past, present, and future behavior of Earth's atmosphere through scientific observation and reasoning* (Atmospheric Science #6).
- *Our understanding of the climate system is improved through observations, theoretical studies, and modeling* (Climate #5).
- *Earth scientists use repeatable observations and testable ideas to understand and explain our planet* (Earth Science #1).
- *The ocean is largely unexplored* (Ocean #7).

Nine of the 11 ESSEPs are syntheses of concepts from at least two of the literacy documents. However, Atmosphere Science Essential Principle 3, *Atmospheric circulations transport matter and energy*, does not correspond with any of the essential principles found in the other three documents. To make this essential principle applicable to the wider Earth system, it was rephrased as, *Matter and energy are transported and transformed by Earth system processes (e.g., tectonic plate motions, denudation, and atmospheric and oceanic circulations)* in the list of ESSEPs. Likewise, one principle in the Earth Science

Literacy Principles, *Earth is 4.6 billion years old*, does not correspond with any essential principles in the other documents. It was included as an ESSEP without modification.

Thirty-nine surveys were completed by conference attendees. Two participants did not provide enough information to allow us to calculate their GEQ score, and their responses were not included in the analysis of the data. The remaining 37 surveys were completed by 11 K–12 teachers and 26 geoscience professors. For Survey 2, respondents were asked to evaluate each of the eleven ESSEPs as very important (V), important (I), of little importance (L), not important (N), and unsure (?). Each ESSEP was scored by converting the Likert-type responses to a score: V = 3, I = 2, L = 1, N = 0. Responses of "unsure" or no response were assigned a score of 0. A mean score for each ESSEP was calculated by normalizing the sum of scored responses against the number of responses. Response rates for individual concepts varied between  $n = 35$  and  $n = 37$ . The count of responses for each category was totaled for each of the 11 ESSEPs. The count totals for the highest category (very important) were used to rank the ESSEPs. Survey 2 also asked respondents to evaluate a set of five liberal learning outcomes supported by the Association of American Colleges and Universities (2000). Those data do not address the educator perspectives of ESS literacy, and the results are not presented here.

## LIMITATIONS

The surveys targeted geoscience professors, and K–12 teachers attendees to the 2009 Geological Society of America (GSA) annual meeting. Of the nearly 6,500 attendees at the meeting, 3,254 were geoscientists and 86 of them were K–12 teachers (M. Cumiskey, personal communication, July 12, 2010). Survey 1 included 25 geoscientists and 11 K–12

TABLE II: Descriptive statistics for respondents of Survey 1 and Survey 2.

	Survey 1	Survey 2
GEQ: All	<b>Mean = 5.58</b> <i>n</i> = 36	<b>Mean = 5.36</b> <i>n</i> = 37
	Expert <i>n</i> = 11	Expert <i>n</i> = 12
	Professional <i>n</i> = 4	Professional <i>n</i> = 3
	Novice <i>n</i> = 21	Novice <i>n</i> = 22
GEQ: K–12	<b>Mean = 1.91</b> <i>n</i> = 11	<b>Mean = 4.09</b> <i>n</i> = 11
	Expert <i>n</i> = 0	Expert <i>n</i> = 3
	Professional <i>n</i> = 0	Professional <i>n</i> = 0
	Novice <i>n</i> = 11	Novice <i>n</i> = 8
GEQ: Geoscience Professor/Geologist	<b>Mean = 7.19</b> <i>n</i> = 25	<b>Mean = 5.90</b> <i>n</i> = 26
	Expert <i>n</i> = 11	Expert <i>n</i> = 9
	Professional <i>n</i> = 4	Professional <i>n</i> = 3
	Novice <i>n</i> = 10	Novice <i>n</i> = 14
Age	<b>Mean = 47.0</b>	<b>Mean = 45.3<sup>1</sup></b>
	Median = 46.2	Median = 47.0
	Range = (28–73)	Range = (23–62)
Ethnicity	100% Caucasian	85% Caucasian
		8% Latino
		7% Other
Gender	Female: 44%	Female: 41%
	Male: 56%	Male: 59%
K–12	Average years of experience: 7	Average years of experience: 7
	( <i>n</i> = 11)	( <i>n</i> = 11)

<sup>1</sup>Seven subjects in Survey 2 did not include their age.

teachers and Survey 2 included 26 geoscientists and 11 K–12 teachers. The sample for each survey represents less than 1% of geoscientists and 12.79% of teachers in attendance. Hence, we are limited by our sample in representing the population in attendance as well as the self-selection of attendees to the 2009 GSA annual meeting.

The integrated list of ESSEPs was created out of necessity as no community-wide effort has been initiated to integrate the principles espoused by the four Earth-relevant communities. Because the list was generated by one individual, the ESSEP list presented here was not developed through the same community consensus process used in the development of the Earth Science, Climate, Atmospheric Science, and Ocean Literacy Principles. A description of the community consensus process used to develop the Earth-relevant literacy documents may be found in Wyssession et al. (2012). Since the ESSEPs are highly representative of the original documents, we expect the results of this study would strongly correlate to geoscience educators' perspectives of the original four Earth-relevant documents (Table I).

As will be seen in the Results section, our results in Survey 2 do not appear to have been influenced by the order in which they were presented to participants. However, because we did not randomize our list, we acknowledge that the potential exists for the results to have been affected by a question order bias (Krosnick and Alwin, 1987; Schuman and Presser, 1981).

## RESULTS

The participant populations for the two surveys were highly similar with respect to gender balance, average age, ethnicity, and professional status (Table II). The K–12 teacher participants for both surveys had an average of seven years of experience at the time of the survey. The number of participants in each category of expertise as identified by GEQ scores was well balanced. The only substantial difference between the two survey populations was in the GEQ score of the K–12 and geoscientist subpopulations, indicating the unsurprising differences in geoscience experience. Overall, results from K–12 teachers and geoscience professors are presented as one dataset that represents the range of educator perspectives from attendees to the 2009 GSA annual meeting. We do present a Mann-Whitney test that assesses differences between K–12 teachers' and geoscience professors' responses in Survey 2.

### Survey 1—Results

Emergent themes from the survey question, *What role does Earth science play in creating a scientifically literate public?* are provided in Fig. 1. The most common responses included statements about the importance of Earth Science for public decision-making. The responses included a range of Earth Science-related public concerns, such as "hazard/natural disaster planning," "building codes," "weather and climate," and "impacts the economy." Several comments expressed that "we live on Earth, so Earth Science is a keystone of a scientifically literate public." We grouped similar responses

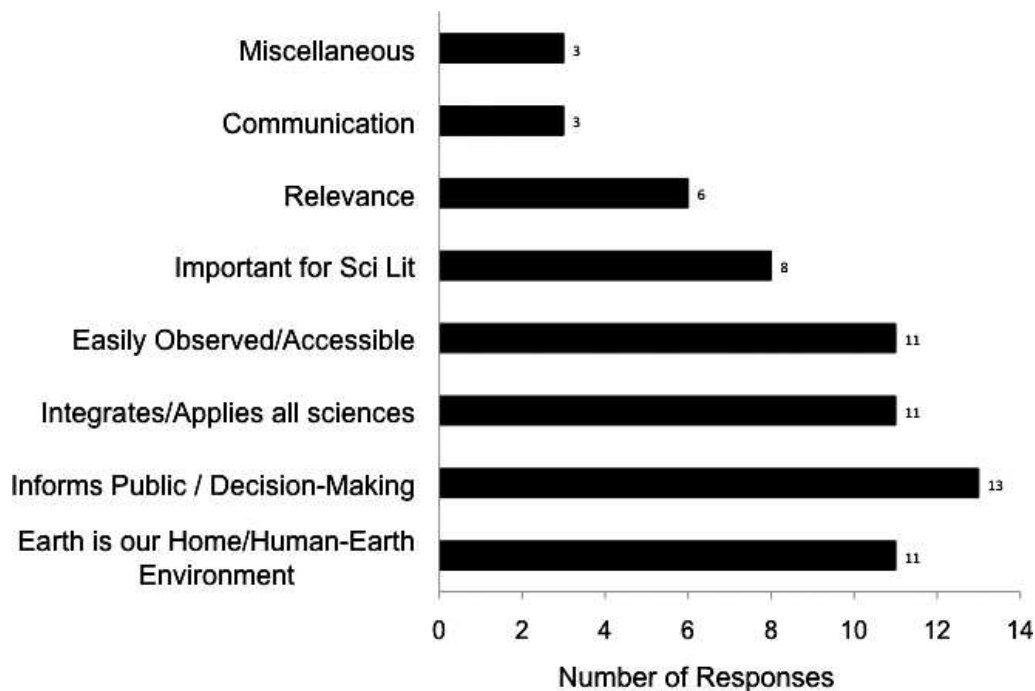


FIGURE 1: Categorized responses from Survey 1, Question 4: *What role does Earth science play in creating a scientifically literate public?* Thirty-six participants' open responses are coded into seven categories, with three miscellaneous responses not graphed. Many responses to this question describe more than one theme and are coded into multiple categories; therefore, 63 responses are represented in the graph.

referring to Earth as our "home" with responses about the human–Earth connection. A third common theme was the integrative nature of the Earth Sciences. Participants viewed Earth Science as a "branch of science that synthesizes and applies physics, biology, and chemistry." Several responses also noted that the Earth Sciences are "tangible," "experienced everyday," "concrete," and "easily observed." This category, Easily Observed, groups responses referring to the accessibility of the Earth Science content for the general public. (For a complete list of all coded responses for Survey 1, please see the supplemental document available at: <http://dx.doi.org/10.5408/11-253s1>).

Formal and informal education experiences were common themes that emerge from responses to the question, *What experiences are most important for building an Earth science literate public?* (Fig. 2). Specifically, participants wanted to see "early exposure in the classroom," "Earth Science courses in the high school curriculum," and modern pedagogical techniques, such as "inquiry," "problem-based learning," "problem solving," "observation of models," and "computer simulations." Experiences in nature (unspecified) and field experiences (specifically) were highly ranked responses for both groups as important experiences necessary for building ESS literacy. Of the 16 responses coded for the Field Experience category, the word *field* appears 15 times. For the Observing and Experiencing Nature category, most responses included descriptions of informal learning experiences, such as:

- "Family experiences in the outdoors";
- "Visiting diverse landscapes";
- "Time exploring and experiencing nature"; and

- "Hands-on rock, mineral, fossil collecting and landscape viewing."

As with the preceding question, participants noted the personal and local relevance of Earth Science topics and the need for hands-on and informal science education experiences.

The top ranked theme for the question, *Describe the three biggest hurdles facing the geoscience education community in promoting Earth science literacy for all people,* was the lack of respect for Earth Science as a serious science (Fig. 3). Eighteen responses specifically refer to this problem of public perception, including:

- "Earth Science is for students not good at sciences";
- "Lack of respect and access to Earth Science learning in K–12";
- "Perception of Earth Science as rocks for jocks";
- "Earth Science has an image problem";
- "Weak representation in state standards"; and
- "Not recognized as a serious science against biology, chemistry, and physics"

Participants most frequently referred to problems with public understanding of the relevance of Earth Science, inadequate content knowledge, religion, and poor communication by geoscientists. Ten participants included responses related to the issue of intelligent design and "conflicts between religion and scientific process" as a hurdle for ESS literacy. Other less common responses included K–12 system problems, public apathy, politics, lack of funding, and the disconnection between people and nature. Where appropriate, comments such as "weak representation in

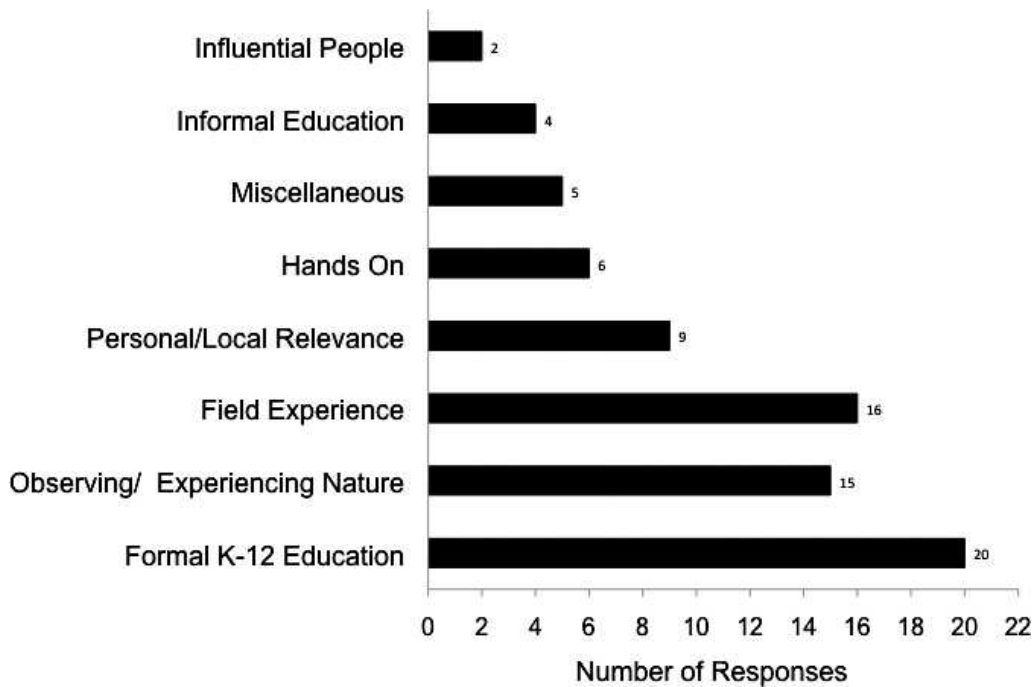


FIGURE 2: Categorized responses from Survey 1, Question 5: *Which experiences are most important for building Earth science literacy?* Thirty-six participants’ open responses are coded into seven categories, with five responses coded under miscellaneous responses not graphed. Several responses were coded into multiple categories; therefore, 72 statements are represented in the graph.

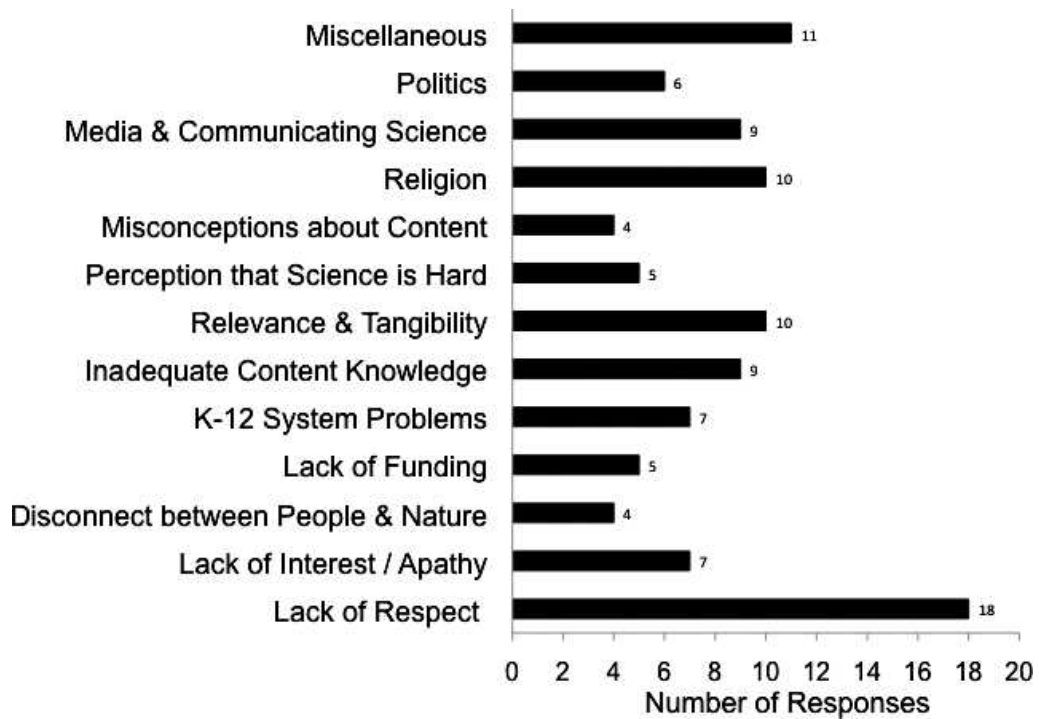


FIGURE 3: Categorized responses from Survey 1, Question 6: *Describe the THREE biggest hurdles facing the geoscience education community in promoting Earth science literacy.* Thirty-six participants’ open-responses are coded into 13 categories, with 11 miscellaneous responses not graphed. Several responses were coded into multiple categories; therefore, 94 statements are represented in the graph.

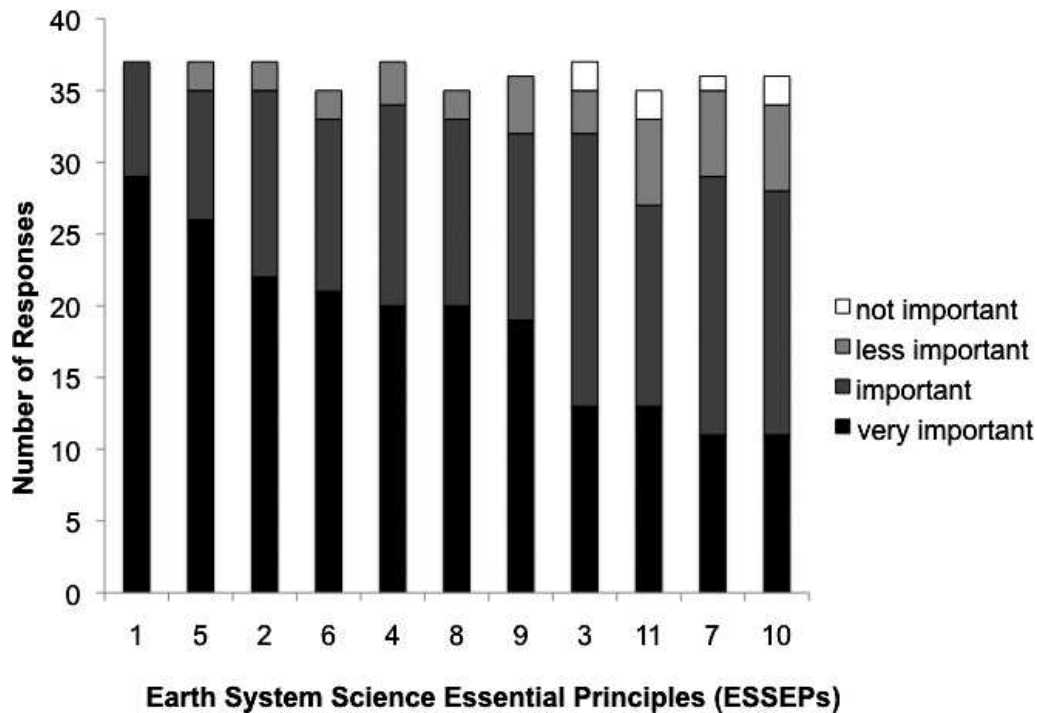


FIGURE 4: Categorized responses from Survey 2 for each Earth System Science Essential Principle (ESSEP). The ESSEPs are rank ordered from left to right based on the highest number of “very important” ratings. ESSEP numbers correspond to numbered list in Table I.

state standards,” were dual-coded into multiple categories (Lack of Respect and K–12 System).

### Survey 2—Results

All participants universally agreed that ESSEP 1, *Exploration of Earth Systems occurs through observations, scientific reasoning, and modeling*, is either an important or very important principle for undergraduate nonscience majors course (Fig. 4). Indeed, over half of the survey participants indicated that 7 of the 11 ESSEPs were very important concepts to teach in an Earth Science course. However, ESSEPs 7, 10, and 11 are identified as having low importance: ESSEP 7, *Natural disasters and climate change threaten human civilization* received six responses of “little importance” and one response of “not important”; ESSEP 10, *Earth has a multifaceted ocean that covers most of Earth’s surface*, and ESSEP 11, *Earth is 4.6 billion years old*, each received six responses of “little importance” and two responses of “not important.”

Responses to Survey 2 were analyzed using the dimension reduction technique of factor analysis to identify any underlying structure in the pattern of responses from participants. Factor analysis allows us to evaluate whether or not ESSEPs can be grouped in a way that explains patterns of variance in the data (Table III). Four factors were identified as having an eigenvalue greater than 1.0. The Kaiser criterion suggests that any factors with eigenvalues greater than 1.0 should be considered for an exploratory factor analysis (Kaiser, 1958). The component matrix indicates that the third and fourth factors each explained less than 10% of the variance. The factor loadings for the fourth factor indicated that the correlations between the item and the fourth factor were lower than correlations (or

loadings) with other factors. This indicates that a four-factor solution is not the best simple solution for the data. Subsequently, we conducted a three-factor analysis with varimax rotation to model the data. This approach explained 66.2% of the variance in the data. The first factor explained 39.4% of the variance in the data and includes ESSEPs 1, 6, 7, 8, and 9. Factor 2 includes ESSEPs 2, 3, and 5 and explains 20.9% of the variance. Factor 3 includes ESSEPs 4, 10, and 11 and explains 19.1% of the variance. Factor 1 is labeled Earth and Life because all of the ESSEPs included in that factor involve interactions between the biosphere or humans and the Earth. All of the ESSEPs that are included in Factor 2 can be grouped as Earth Systems. Factor 3 presents more diverse content than the other two factors, including matter and energy cycling (ESSEP 4), the ocean (ESSEP 10), and the Earth’s age (ESSEP 11). This third set of ESSEPs is labeled as Earth Facts. The first two of the essential principles in this factor set might appear to belong in the Earth System factor set. However, as discussed below, our interpretation of how these two principles were perceived by the survey participants justifies their inclusion as Earth Facts.

A Mann-Whitney test of independent samples was run to look for potential differences between the K–12 teacher and geoscience professor responses. With this non-parametric test, we compared the medians of the ranked scores for the 11 K–12 teachers and the 26 geoscience professors on the three factors we identified. This analysis revealed that for Factors 2 (Earth Systems) and 3 (Earth Facts) no statistical difference existed between K–12 teachers and geoscience professors. A significant difference did exist between K–12 teachers and geoscience professors on their ratings of Factor 1 (Earth and Life) ( $p < 0.023$ ). The data show that K–12 teachers ranked ESSEPs related to Earth and Life as having

TABLE III: Factor loadings for Earth System Science Essential Principles (ESSEPs). Loadings represent the correlation between the item and the factor. Means and standard deviations are computed using the z-scores for each factor, which provides the basis for the Mann-Whitney test.

Earth System Essential Principles	Factor Loading	K–12 Teacher	Geoscience Professor
<i>Factor 1: Earth and Life</i>			
1. Exploration of Earth systems occur through observations, scientific reasoning, and modeling.	.649	Mean = .489 <sup>1</sup> SD = .512	Mean = –.207 SD = 1.089
6. Humans are inextricably interconnected to the geosphere, hydrosphere, and atmosphere.	.833		
7. Natural disasters and climate change threaten human civilization.	.672		
8. Humans have become a significant agent of change to the geosphere, hydrosphere, and atmosphere.	.740		
9. The biosphere depends on and affects the hydrosphere, the atmosphere, and the geosphere.	.610		
<i>Factor 2: Earth Systems</i>			
2. Earth systems involve complex interactions between rock, water, air, and life.	.805	Mean = .207 SD = 1.068	Mean = –.088 SD = .978
3. The Sun is the primary source of energy for Earth’s climate system.	.696		
5. Earth systems are continuously changing.	.819		
<i>Factor 3: Earth Facts</i>			
4. Matter and energy are transported and transformed by Earth system processes (e.g., tectonic plate motions, denudation, and atmospheric and oceanic circulations).	.648	Mean = .088 SD = .958	Mean = –.037 SD = 1.033
10. Earth has a multifaceted ocean that covers most of Earth’s surface.	.748		
11. Earth is 4.6 billion years old.	.800		

<sup>1</sup>Means and standard deviations are computed using z-scores for each factor by group.

higher importance than geoscience professors. K–12 teachers also showed less variability in their rankings as indicated by the lower standard deviation (Table III).

## DISCUSSION

### Survey 1

The responses from Survey 1 reflect common themes that often arise at geoscience education sessions during GSA meetings. The respondents noted the human relevance of geoscience, its importance for informed decision-making and the accessibility of the content for laypersons. The Earth Sciences face substantial obstacles, which include the lack of respect for Earth Science as a rigorous science, poor representation of the Earth Sciences by the media, and lack of public awareness about the relevance of Earth Science, are impediments to ESS literacy. To promote ESS literacy, the respondents in our survey indicated support for more emphasis to be placed on the Earth Sciences in K–12 science education, more opportunities for formal and informal field experiences, and an emphasis on locally relevant examples for the public. The responses to the free-response questions in Survey 1 articulated the geoscience educators’ awareness of a substantial public image problem for the Earth Sciences. The new *Framework for K–12 Science Education* provides some hope for improved quality in ESS education since Earth and Space Science content has been identified as one of the four

Disciplinary Core Ideas (National Research Council, 2011). If the developers of national standards use the Crosscutting Themes and Scientific Practices presented in the framework to develop a quality set of Earth Science standards, K–12 ESS education may be greatly enhanced across the country.

### Survey 2

The factor analysis conducted on Survey 2 provides insight into the underlying constructs for each of the ESSEPs (Table III). Factor 1, Earth and Life, includes ESSEPs related to human activities or the biosphere. Factor 2, Earth Systems, groups the ESSEPs related to Earth Systems. Factor 3, Earth Facts, includes three rather distinct ESSEPs. At first glance, ESSEP 4, *Matter and energy are transported and transformed by Earth system processes (e.g., tectonic plate motions, denudation, and atmospheric and oceanic circulations)*, would appear to belong in the Earth Systems category. As stated previously, this ESSEP was expanded from an essential principle that was aligned with only one of the four original documents to have broader ESS relevance (Atmospheric Science Literacy, 2008). We suggest that it loads on the Earth Facts factor rather than the Earth System factor because the parenthetical information that was included with the principle may have focused the respondents’ attention on the list of specific facts, rather than the broad statements of the ESSEPs included in the Earth System factor. Likewise, ESSEP 10, *Earth has a multifaceted ocean that covers most of Earth’s surface*, and ESSEP 11, *The*



*Earth is 4.6 billion years old*, are both facts pertaining to a narrow range of Earth Science content. Supporting our interpretation is a “write-in” response by one participant, indicating that ESSEP 11 is too limiting. The participant described the “ability to understand processes across scales of distance and time” as a very important concept that, in his opinion, was more valuable than knowing specifically that the Earth is 4.6 billion years old. The need for a general appreciation of the magnitude of the scales of time and space, rather than knowledge of a precise date, also appears in another analysis of the four literacy documents (Ross and Duggan-Haas, 2010).

A reliability analysis was used to identify whether the geoscience educators who participated in this study rated the ESSEPs consistently or if any particular ESSEPs elicited a more diverse range of responses. Survey 2 had a high reliability, Cronbach’s  $\alpha = 0.83$ , indicating a high level of consistency between participants’ valuations. However, we noted a relatively higher standard deviation in responses for ESSEP 11, *The Earth is 4.6 billion years old*. Not surprisingly, Cronbach’s alpha for the ESSEP list would increase to 0.84 if ESSEP 11 were removed. The removal of any one of the other ESSEPs would decrease Cronbach’s alpha, indicating that they contribute to the overall reliability of the scale of ESSEPs. This, paired with the low ratings for ESSEP 11, supports our assertion that geoscience educators have diverse viewpoints on ESSEP 11, possibly stemming from the principle’s wording.

When the responses of the Survey 2 participants are viewed as two subpopulations of K–12 teachers and geoscience professors, the Mann-Whitney test of independent samples shows significantly different medians for the responses on the set of concepts related to Earth and Life. The K–12 teachers rated this set of ESSEPs more highly and are more unified in their responses, whereas geoscience professors rated Earth and Life lower and are more divergent in their responses.

## General Discussion

The contrast in results from Survey 1 and 2 present an interesting juxtaposition between the role of Earth Sciences in people’s lives and geoscience educators’ valuations of what to focus on when teaching undergraduate non-majors. Survey 1 presents common themes discussed in the geosciences regarding underrepresentation of Earth Science in K–12 as a rigorous science (American Geological Institute, 2008) and a poorly informed public (Fig. 3). Participants identify personal and local relevance as critical for promoting ESS literacy (Fig. 2). Despite the presence of these themes in Survey 1, responses in Survey 2 demonstrate that geoscience educators place greater importance on systems concepts over specific topics (Fig. 4). Geoscience educators understand the importance of a systems perspective for deep scientific understanding of natural hazards and climate change. The difference in perspectives conveyed through these two surveys likely represents a difference between geoscientists’ goals for education in an instructional setting versus advocacy for public understanding of science.

The topic of religion provides another interesting point of comparison between results from the two surveys. Ten respondents to Survey 1 noted religion as a hurdle to public ESS literacy (Fig. 3). Likewise, many states are seeing proposed legislation to weaken the teaching of evolution

and promote the teaching of intelligent design in public K–12 science programs (Berkman et al., 2008). The scientifically determined age of the Earth is a contentious issue for some fundamental religious denominations, so it was surprising to us that respondents of Survey 2 identified the age of the Earth as one of the less important concepts to teach in undergraduate nonmajors courses. We expected teachers and geoscience professors to consider this to be a very important concept for nonscience majors. We speculate that this ESSEP may have been perceived as too focused on one fact rather than on a more broadly based deep time concept such as: *The vast magnitudes of deep space and deep time are requisite for the evolution of the universe and of life*. Differences in results from Survey 1 and 2 are indicative of more nuanced issues associated with teaching about Earth and Life and the age of the Earth than can be revealed through our surveys. We interpret our results to suggest that the fact-like nature of ESSEP 11 makes it undesirable for some geoscience educators. The question of whether a specific fact about the age of the Earth or a broader appreciation of the scale of deep time and space would be supported as an essential principle by typical Earth Science educators needs to be addressed in future research.

Teachers may be more attuned to the need of teaching the interconnectedness of humanity and the Earth. This can be seen in the K–12 teachers’ comments in Survey 1 that the public lacks an awareness of the relevance of Earth Science, and in results from Survey 2 that suggest K–12 teachers, more so than geoscience professors, strongly value ESSEPs related to Earth and Life. We wish to point out to geoscience educators that the general education requirement of taking a year of science courses during undergraduate training has a significant impact on the science literacy of Americans (Miller, 2010). Any improvements to these courses are likely to further contribute to American’s science literacy. Therefore, we advocate a highly focused, small set of essential principles be included in undergraduate nonscience major courses geared at improving public science literacy.

## CONCLUSIONS

This study presents insights into what K–12 teachers and geoscience professors perceive as important life experiences and hurdles to achieving Earth Science literacy. While formal education is highly valued, experiencing nature and appreciating Earth’s relevance are also considered to be valuable. The present study represents the first attempt to assess the geoscience education community’s support for 11 Earth System Science Essential Principles that are themselves based on 31 essential principles generated within four Earth System research communities. More than half of the survey participants rated 7 of the 11 essential principles as being very important concepts to teach in an Earth Science course. We interpret this to suggest that, in general, geoscience educators support most of the 31 essential principles generated from community-wide efforts. However, as Ross and Duggan-Hass (2010) point out, when treated as four independent lists, the sheer number of essential principles is overwhelming to a nonscientist. In itself, this will hinder widespread gains in science literacy. We would support any community-wide efforts to revisit this topic and generate a consensus-based, integrated list of ESSEPs, and to develop a fully integrated definition of ESS literacy. We suggest that

those efforts would have to consider abandoning a canonical list of concepts in favor of developing public understanding of Earth Science through the K–12 and undergraduate introductory course content.

The geoscience education community is uniquely positioned to influence public understanding of science as a whole because geoscience content is relevant and accessible to the public. Survey 1 results demonstrate that the geoscience education community values the integration of science and community for building enduring public science literacy (see also Roth and Lee, 2004). Although our results critically evaluate the content and language of the sets of literacy principles, we believe that the community-based sets of principles have already served their intended purpose by positively influencing Earth Science education. Work from the Earth Science Literacy Principles (Earth Science Literacy Initiative, 2009) can be seen in the *Framework for K–12 Science Education* (National Research Council, 2011), which is being used to develop the next generation of science standards.

## FUTURE WORK

The contrasting results of these two surveys call for expanded studies of geoscience educators' perspectives on the meaning of Earth Systems Science Literacy and on the valuation of specific facts, such as the age of the Earth. Future work should encompass a larger sample of K–12 teachers and geoscience professors from all types of tertiary education in order to examine the influence of discourse differences between university professors and K–12 educators.

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**APPENDIX A: Geoscience Experience Questionnaire (with point values in italics).**

1. Did you take a geology or earth science course in high school? .....	(0.25)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
2. Did you take a geology or earth science course as an undergraduate?.....	(0.25)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
3. Did you take a geology or earth science course in graduate school?	(no points)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
<b>IF YES, MOVE TO 4. IF NO, MOVE TO 5.</b>			
4. How many graduate courses in geology or earth science did you take? .....			
<input type="checkbox"/> 0 <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 or more	(0.25 x number of courses)		
5. Have you ever held an internship in geology or earth science, or worked as a research assistant in geology or earth science? .....	(no points)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
<b>IF YES, MOVE TO 6. IF NO, MOVE TO 9.</b>			
6. Were you an Undergraduate Research Assistant? .....	(0.25)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
7. Were you a Graduate Research Assistant? .....	(0.25)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
8. Were you a Research Assistant in some other capacity? ...	(0.25)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
9. Have you ever worked professionally as a geologist or earth scientist? .....	(no points)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
<b>IF NO, MOVE TO 11.</b>			
10. How many years did you work as a professional geologist? .....			
<input type="checkbox"/> less than 5 years <input type="checkbox"/> 5-10 years <input type="checkbox"/> more than 10 years	(1 point)   (5 points)   (10 points)		
11. Did you work as a Middle School or High School Teacher in a high school geology or earth science course? .....	(no points)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
<b>IF NO, MOVE TO 13.</b>			
12. How many years did you work as a teacher? .....			
<input type="checkbox"/> less than 5 years <input type="checkbox"/> 5-10 years <input type="checkbox"/> more than 10 years	(no points)		
13. Did you work as a College Professor in geology or earth science? .....	(no points)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
<b>IF NO, MOVE TO 15.</b>			
14. Have you done geoscience education research?	(no points)	<input type="checkbox"/> NO	<input type="checkbox"/> YES
15. Have you ever worked in informal science education or outreach?	(no points)	<input type="checkbox"/> NO	<input type="checkbox"/> YES

**APPENDIX B: Survey 1.**

This survey is intended to evaluate your perspectives about Earth Science literacy.

<p>“The science-literate person is one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes.” —AAAS, <i>Science for All Americans</i> (1989, 1990)</p>	<p>Science literacy is “the level of understanding of science and technology needed to function in a modern industrial society. This ... does not imply an ideal level of understanding, but rather a minimal threshold level.” —Jon Miller, at the 2007 Annual Meeting of AAAS, as reported in Hobson (2008)</p>
Which definition of <b>science literacy</b> more closely aligns with your personal view?	
AAAS <i>Science for All Americans</i> definition Why?	Jon Miller’s definition
How would you measure whether or not someone is <b>Earth science-literate</b> ?	
What role does <b>Earth science</b> play in creating a scientifically literate public?	
Which experiences are most important for building <b>Earth science literacy</b> ?	
Describe the <b>THREE</b> biggest hurdles facing the geoscience education community in promoting <b>Earth science literacy</b> for <u>all people</u> .	

## APPENDIX C: Survey 2.

Many nonscience majors take, at most, one physical science course in college.

Please evaluate the relative importance of the following concepts and skills for nonscience majors enrolled in an Earth Systems Science course.

V = Very Important; I = Important; L = Of Little Importance; N = Not Important; ? = Unsure

Concept	Importance				
	V	I	L	N	?
Exploration of Earth systems occur through observations, scientific reasoning, and modeling.	V	I	L	N	?
Earth systems involve complex interactions between rock, water, air, and life.	V	I	L	N	?
The Sun is the primary source of energy for Earth's climate system.	V	I	L	N	?
Matter and energy are transported and transformed by Earth system processes (e.g., tectonic plate motions, denudation, and atmospheric and oceanic circulations).	V	I	L	N	?
Earth systems are continuously changing.	V	I	L	N	?
Humans are inextricably interconnected to the geosphere, hydrosphere, and atmosphere.	V	I	L	N	?
Natural disasters and climate change threaten human civilization.	V	I	L	N	?
Humans have become a significant agent of change to the geosphere, hydrosphere, and atmosphere.	V	I	L	N	?
The biosphere depends on and affects the hydrosphere, the atmosphere, and the geosphere.	V	I	L	N	?
Earth has a multifaceted ocean that covers most of Earth's surface.	V	I	L	N	?
Earth is 4.6 billion years old.	V	I	L	N	?
Ethical issues or ethical values.	V	I	L	N	?
Demonstration of advanced communication skills, especially writing.	V	I	L	N	?
Demonstration of critical thinking and problem solving.	V	I	L	N	?
Demonstration of cross-cultural understanding in the context of the global environment.	V	I	L	N	?
Demonstration of team work / collaborative learning.	V	I	L	N	?
OTHER:	V	I	L	N	?
Have you heard or read about the <i>Earth Science Literacy Initiative</i> ?	YES		NO		
Have you heard or read about Liberal Learning Goals?	YES		NO		