Essential science knowledge for non-science majors: an electronic survey of The Ohio Academy of Science members and associates

MARY D. GAHBAUER[1], Department of Biology and Earth Science, Otterbein University, Westerville, Ohio, USA

ABSTRACT. As science and technology increasingly characterize our civilization, there is a growing need for the general population to achieve "scientific literacy." The meaning of this attractive but ill-defined term varies within political, educational, and social contexts. This paper reports a study of what scientific literacy is appropriate in the specific context of undergraduate general science education; for most students this is their last opportunity for formal learning in science. Members and associates of The Ohio Academy of Science (OAS) were surveyed by email to gain their opinions on (1) which topics of science (other than discipline-specific content), and (2) what level of technical detail, are essential for non-science citizens. Responses (N=557) showed a moderately uniform opinion that (1) science should be taught as a stepwise method of knowledge construction and explanation; heavy emphasis is needed on evidence and its uses in science in contrast to everyday thinking and pseudoscience; science should be related to other disciplines of study and to "real world" personal, social and global problems, and that (2) the appropriate level scientific literacy is general rather than more technical. Exceptions were the definitions of theory, hypothesis and law, for which more technical, rather than general, versions were favored. These aspects of scientific understanding correspond more closely to the non-expert "consumer", "competent outsider", or "citizens'" science than to the "scientific insider", or "scientists'" science. This research may have implications for curricular design because scientific reasoning and application of science to real world problems are often not prominent in science courses or texts.

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INTRODUCTION

Only about 5.2 percent of United States civilians are employed in the natural sciences, mathematics, computer science, engineering and architecture (US Census Bureau 2008.) Most of the population—and most undergraduate students—are therefore not likely to find their future in science. Nonetheless, there is a wide consensus among scientists, educators, and policy makers that all people should be scientifically literate. (American Association for the Advancement of Science [AAAS], 1990a, 1993; National Research Council [NRC] 1996, 2011; National Science Teachers Association [NSTA], 2000).

According to *A Framework for K-12 Science Education* (NRC 2011), "Science, engineering, and technology permeate nearly every facet of modern life, and they also hold the key to meeting many of humanity's most pressing current and future challenges. Yet too few U.S. workers have strong backgrounds in these fields and many people lack even fundamental knowledge of them."

Such calls for widespread scientific literacy do not consider what type and level of literacy is desirable, useful, or even possible in specific groups within the population. One group for whom a clear definition of an appropriate literacy is crucial is the very large body of students in college who are non-science majors. These students are nearing the end of their formal education in science, and have the potential to influence the future of our society. The purpose of this study is to identify essential science understanding for non-science majors by surveying members and affiliates of the Ohio Academy of Science (OAS) i.e. those whose profession involves knowledge of science and its uses.

Multiple meanings of the term "scientific literacy"

Teaching science to all students has been expected to benefit both individuals and society since the 19th century (DeBoer 2000), but the nature of the science taught has shifted with the prevailing socio-political climate. For example, because of the focus on national security and scientific advancement in the mid 20th century, what was meant by the newly coined term "science literacy" was knowledge of the principles of academic science (Hurd 1958, McCurdy 1958). By the later 20th century progress in technology had made information so readily available that the term had widened, and scientific literacy could now mean knowledge of how to find science to apply to specific social situations and everyday life (Roberts 2007).

"Scientific literacy" therefore has no fixed significance, and widespread use made it a buzzword signifying

[1]Address correspondence to Mary D. Gahbauer, Department of Biology and Earth Science, Otterbein University, Westerville, OH 43081 USA. E-mail: mgahbauer@otterbein.edu

"everything and nothing" (Feinstein 2011). Despite its extensive literature, there is no consensus on any meaning more specific than "what the general public ought to know about science" (Durant 1993), and groups with different interests (such as science educators, public policy makers, sociologists, journalists, and others) have each developed their own concepts and applications of scientific literacy (Laugksch 2000). Even within science education there is no standard meaning, possibly because the meaning must be appropriate to the context (DeBoer 2000).

The spectrum of meaning of "scientific literacy" has been illustrated by its two extremes (Roberts 2007). Roberts' "Vision I" means knowledge within science concerning its processes and products. This type of knowledge has previously been called "scientists' science" (Gilbert and others 1982), and is typified by the specific content in Benchmarks for Science Literacy (AAAS 1993). At the other extreme Roberts' "Vision II" relates to human affairs and views science as a competent outsider. This has also been termed "functional scientific literacy" (Ryder 2001), "civic science" (Miller 2002), and "citizen science" (Roth and Barton 2004). Such polarization of meaning is also expressed as: very few will be producers of knowledge, but all will be consumers (Millar 2008); doing or using science (Hazen and Trefil 2009); being a scientific insider or a competent outsider who can use relevant sources of expertise (Feinstein 2011).

It is worth noting that there has been no summative assessment of any approach to general scientific literacy. Feinstein notes the irony that science, although built on empiricism, makes assumptions of the benefits of widespread scientific literacy in the absence of evidence (Feinstein 2011). Lack of evidence is not surprising, if Shamos' opinion is correct: that there is "not the slightest possibility" of actually achieving literacy concerning science in the general population, as the study of science is cumulative and too difficult. He and others thought that it would be more useful to focus on the use of technology in general science courses, as this is where personal benefits are actually derived (Shamos 1995, Sjφberg 1997).

The instructor's problem at a local level

Guidelines such as Benchmarks and the National Science Education Standards set out factual knowledge and conceptual understanding for each grade level. The aim is a cumulative understanding of science by grade 12, but instructors at the college level often find that non-science majors lack this understanding and feel disenfranchised (Straits and others 2011). Therefore non-majors' undergraduate science courses represent a last, brief chance to develop a functional understanding of science before students go out into a society that is largely shaped by science. The aim of the present study is to identify the most appropriate type and level of science on the spectrum of scientific literacy (between introductory majors' science, or "scientists' science", and the more humanistic "citizens'" or "functional" science), is most appropriate to non-science majors.

Although "there is general agreement that students can't be scientifically literate if they don't know any science subject matter" (Roberts 2007), factual content is not a focus of this study as it has been detailed elsewhere (AAAS 1993, Hazen and Trefil 2009), is discipline-specific, and is not always the instructor's choice. However the way in which content is presented can teach concepts such as: science as a process of using empirical evidence to construct and validate knowledge of the natural world (related to Roberts' Vision I, or "scientists science" above); how science can be used to address personal, social, and global problems related to science (related to Roberts' Vision II, or "citizens' science" above): and also scientific thought as a type of fundamental literacy, contrasted to casual everyday thought and pseudoscience (also related to Roberts' Vision II and "citizens' science" above).

MATERIALS AND METHODS

Design of the survey

Topics included in the survey were aspects of scientific literacy prominent in the literature: the scope and limits of science; key terms in science; sources of knowledge in science; evidence in science; scientific thinking; science vs. pseudoscience; methods of science; experimental design; interpretation of data; justified conclusions; history of science; cross-curricular skills; interaction of science and society. For each topic a series of statements was generated along the spectrum of literacy from "not essential for non-majors" through general statements about science ("citizens' science"), to more technical aspects of the topic ("scientists' science.) All topics and statements were developed with the advice of a specialist in undergraduate science education.

Respondents were asked whether each topic was essential for non-science majors, and if so, to select among the statements on that topic for those they believed essential and at an appropriate level of technicality for non-science majors. Multiple selections could be made, and comments were solicited. The survey was constructed electronically in SurveyMonkey™, and with IRB permission, the link was distributed from the OAS office to members and affiliates. A summary of the topics and statements of the survey is shown in Table 1.

Validity of the survey

The response rate (a measure of how well the survey reports OAS opinion) was maximized by limiting survey length, sending a reminder, guaranteeing anonymity, and offering a summary of results (Deutskens and others 2004). That the statements could be read as intended was confirmed by discussing the survey with 15 science students (including non-native English speakers) and administering it to 272 non-science students with additional answer choices: "understand but don't know" and "don't understand." Non-science students answered "don't understand" to an average of 1.5 out of 95 substantive questions.

RESULTS

The survey closed after one month with 557 respondents. Of these 31.0 percent self-identified as science educators, 12.0 percent as scientists in business or industry, 8.4 percent as primarily research scientists, 7.4 percent as science students, 3.5 percent as scientists in government, 3.4 percent as engineers or mathematicians, 3.1 percent as educational administrators, 2.5 percent as health care professionals, 0 .9 percent as lawyers, 7.7 percent as "other," and 1.4 percent as "non-science other." Two thirds of respondents self-reported as being in mid- or senior career; others were students or in early career, or had retired/emeritus status.

The estimated overall response rate to the survey is 20-25 percent (the actual response rate is unknown due to failure of the distributing hardware) which corresponds to the median rate of 26.4 percent in an analysis of online professional surveys (Hamilton 2009). The occupational profile of respondents reflects that of the OAS listserves used (Elfner 2011); response representativeness is important in validity (Cook and others 2000). Also an indicator of validity, of 395 comments submitted by OAS respondents, only 12 contained evidence of difficulty understanding statements, and six of those concerned the grammar of one statement.

Support for each of the 95 survey statements is detailed in Table 1. Opinions were moderately uniform across occupational groups; the standard deviation (SD) from the mean percent support for each survey statement varied from one to 21.8, the most frequent being 10. Among four groups (research scientists, science educators, scientists in business or industry, and scientists in government) opinions were more closely uniform; the SD varied from one to 15.8, most frequent being six.

Government scientists, scientists in math or engineering, research scientists and lawyers were overall less inclined to find the content of survey statements essential for non-majors. Health professionals, educational administrators, "other", and science students were more inclusive, and overall found more survey content essential to non-majors. This disparity might arise because career scientists have a deeper understanding of the survey topics, and find it difficult to expect such understanding from non-science students.

The stage of career had little effect on opinion except that students were more inclined to favor statements at a simple level than were other groups.

Most supported statements

Of all 95 survey statements the one most favored by all respondents (90.3 percent) was the most fundamental: "Science is a way of understanding the natural world (universe)" (Topic 1.) Other statements most strongly supported (> 70 percent overall) of respondents are listed in Table 2.

Statements from all topics except "Interpretation of data, drawing conclusions," and "History of science" are included in the most supported list; however, they are notably general in nature, and few could be interpreted as "scientists' science."

Least supported statements

The least favored statements were negative; "This topic is not essential for non-science majors" appeared in 12 topics, but was selected by less than 7 percent of respondents (median 2.7 percent). Other negative statements with very low support (< 15 percent) include a reference to right cerebral hemisphere dominance hindering science learning, and a statement that widespread scientific literacy is impossible to achieve (Shamos 1995).

Statements with low support (15 to 50 percent) for non-majors' courses concern more technical aspects of science, including normal and revolutionary science, inductive and hypothetico-deductive thinking, falsification, probability, subjective influences on scientific thinking, experimental design, sensitivity and specificity of tests, multiple hypotheses, negative results, reading original papers rather than stories of science,

TABLE 1
Survey questions, percent of occupational groups of respondents supporting each statement as essential in non-majors' science, and overall support of respondents for each topic statement

Survey results by occupation for groups of five or more

	Science education	Science industry/ business	Science research	Science student	Scientists in government	Other	Engineering mathematician	Health professional	Eductional administrator	Non-science other	SD occupational group support means	Mean percent support overall OAS support for statement
Number of respondents (N=)	172	66	46	41	19	5	19	4	17	8		
1. Scope and Limits of Science												
This topic is not essential for non-majors	0.6	3	4.3	4.9	4.3	12.5	0	7.1	0	12.5	4.6	2.3
Science is a way of understanding the natural world (the universe)	94.8	91	91.5	90.2	90	85.7	84.2	92.9	94.1	87.5	4.5	90.3
Science produces knowledge that is generally reliable	61	53.7	68.1	63	55	62.9	47.4	85.7	70.6	87.5	14.6	61.4
Science can be used to manipulate aspects of the world, life processes, atomic structure, energy transfer	59.9	56.7	63.8	58.5	40	60	57.9	64.3	47.1	37.5	10.1	57.6
Science does not produce "the truth" but tentative knowledge that changes with new evicence	72.1	58.2	59.6	63.4	45	62.9	42.1	71.4	64.7	25	19.2	61.6
Science produces estimates of probability, not predictions or certainties	45.3	40.3	51.1	39	45	45.7	15.8	57.1	41.2	25	11.5	43.6
2. What Science is Not												
This topic is not essential for non-majors	0.6	4.5	4.3	0	5.3	0	0	0	0	12.5	4	2
Science is not the same as technology	47.4	46.3	43.5	51.2	42.1	42.9	47.4	53.8	47.1	37.5	4.8	47.2
Science is not a set of facts, but a process of exploration and explanation	78.9	91.4	73.9	83.6	100	80.5	94.7	82.4	92.3	87.1	8.7	84.2

TABLE 1 (cont.)

Science is built on observed evidence; religion is built on faith	66.1	68.7	78.3	67.9	68.4	60	42.1	69.2	76.5	25	16.5	65
Science cannot find answers to moral or ethical questions	49.7	52.2	41.3	56.1	42.1	64.7	47.4	38.5	49.7	50	7.8	48.2
Science can tell us how things work in the universe but not the purpose	62	56.7	56.5	56.1	52.6	70.6	57.9	53.6	62	50	7.7	58.2
3. Key Terms in Science												
This topic is not essential for non-majors	1.7	4.6	4.3	4.9	5	0	0	0	0	0	2.3	2.6
A hypothesis is "an educated guess"	54.1	58.5	42.6	70.7	45	74.3	68.4	78.6	52.9	87.5	15.8	59.1
A theory is not a hunch, but an established explanation of how things work	71.5	56.9	59.6	78	50	74.3	68.4	71.4	58.8	75	9.1	67.8
A law is a rule of how things are related, but not an explanation	44.8	43.1	46.8	68.3	30	51.4	57.9	64.3	52.9	50	14	49.3
A hypothesis does not become a theory even if much evidence supports it	21.5	12.3	19.1	43.9	20	31.4	31.6	21.4	17.6	25	8.7	24.4
A theory does not become a law even even if much evidence supports it	23.3	13.8	17	43.9	20	28.6	31.6	21.4	17.6	25	8.4	25.7
Theories change with new evidence, this strengthens not weakens them	77.3	69.2	68.1	75.6	75	77.1	57.9	85.7	76.5	37.5	13.2	73.3
A hypotheseis is a proposed, researched, testable explanation for phenomenon	73.3	67.7	70.2	68.3	70	68.6	73.7	78.6	76.5	62.5	5.5	70.6
A theory is a broad high-level explanation of natural phenomena, constructed of all reliable, current information	69.8	73.8	74.5	51.6	65.2	51.4	63.2	85.7	82.1	25	18.4	67.4
A law is a statement of relationship that holds true through many observations	64.5	63.1	63.8	51.2	70	48.6	73.7	78.6	64.7	50	10.9	62.4
4. Sources of Knowledge in Science												
This topic is not essential for non-majors	2.3	0	6.4	4.9	0	0	0	0	5.9	0	2.7	2.1
Scientific knowledge is derived from objective evidence	62.8	55.2	48.9	58.5	65	57.1	73.7	57.1	76.5	12.5	17.5	59.7
New knowledge must be reviewed by experts (peer reviewed) before it is accepted	62.3	67.2	61.7	75.6	70	77.1	42.1	78.6	70.6	37.5	14.6	65
New knowledge is published in searchable journals, "the literature"	53.5	62.7	63.8	58.5	65	48.6	36.8	78.6	70.6	37.5	14.6	57.4
Opinion without evidence is not accepted as knowledge even if from famous, powerful or popular sources, or however many people voice it	82.6	83.6	68.1	80.5	75	82.9	63.2	78.6	82.4	87.5	9.1	79

TABLE 1 (cont.)

Science constructs theoretical models and tests them against reality	65.7	56.7	66	56.1	55	65.7	65.7	78.6	64 .7	75	7.5	62.9
Theories tend to be normative until revolutionized by better explanation	40.7	37.3	42.6	36.6	40	60	31.6	57.1	52.9	62.5	10.6	42.8
5. Evidence in Science vs. on the Street												
This topic is not essential for non-majors	1.2	0	6.4	0	0	2.9	0	0	0	0	2	1.5
Evidence is obtained by systematic observation/testing/measurement	83.1	86.6	80.9	87.5	70	80	83.3	85.7	76.5	87.5	5.3	83
Arguments are supported by adequate, relevant evidence	76.7	77.6	72.3	75	55	82.9	66.7	85.7	76.5	62.5	9.7	75
New evidence is thoroughly evaluated, not casually accepted	69.8	68.7	66	65	55	82.9	68.7	85.7	76.5	75	17.7	68.6
Evidence must have a source, anecdotal evidence is not accepted	65.4	61.2	57.4	57.5	60	65.7	38.9	85.7	64.7	75	12.6	59.6
All evidence on a topic must be weighed; it cannot be selected or ignored to suit a particular viewpoint	76.7	80.6	72.3	85	50	65.7	50	78.6	64.7	87.5	12.9	77.2
Patterns in evidence are valuable	57	47.3	46.8	42.5	40	74.3	33.3	64.3	70.6	75	15.1	53.5
Falsification has more impact than verification	37.8	35.8	48.9	45	30	45.7	27.8	28.6	29.4	37.5	7.4	39.3
6. Scientific Thinking												
This topic is not essential for non-majors	1.2	3	4.3	5	5.3	0	0	0	0	12.5	6.3	2.4
Scientific thinking is always objective and unbiased	38.4	45.5	39.1	57.5	31.6	25.7	44.4	57.1	23.5	37.5	11	40.5
Scientific thinking is not kept for "scientific situations;" it applies to everyday life	86	75.8	73.9	75	63.2	80	88.9	100	76.5	75	15.2	80.2
A questioning and skeptical attitude are fundamental to science	74.4	65.2	78.3	65	73.7	71.4	61.1	71.4	64.7	87.5	8.1	71
Mood, sentiment, social and spiritual values play no part in scientific reasoning	37.8	43.9	39.1	42.5	26.3	37.1	33.3	42.9	52.9	50	9.6	39.4
Scientific thinking is developed, it is not just common sense	57	58.2	56.5	57.5	68.4	71.4	55.6	85.7	52.9	37.5	21.8	60.1
Scientific thinking identifies the relevance and importance of ideas	37.8	37.9	41.3	45	42.1	51.4	44.4	57.1	47.1	50	9.6	41.6
Reasoning in science is often inductive or hypothetico-deductive	32	15.2	41.3	30	5.3	25.7	27.8	50	35.3	37.5	15.1	29

TABLE 1 (cont.)

Scientists' thinking can be influenced by social, employment and academic factors	43	50	45.7	42.5	36.8	60	33.3	42.9	52.9	25	9.5	45.2
7. Science and Pseudoscience												
This topic is not essential for non-majors	4.1	1.5	8.5	2.5	0	5.7	16.3	0	0	12.5	5.6	4.2
Knowledge and methods are openly published, not kept as mysterious secrets	76	79.1	72.3	72.5	90	68.6	66.7	85.7	94.1	75	14.4	75.8
Ideas are linked with logical reasoning, not loosely linked	55.6	61.2	57.4	57.5	90	71.4	66.7	85.7	64.7	62.5	13.9	59.3
Science seeks to explain new knowledge in the light of previous knowledge; it does not ignore it	74.3	80.6	68.1	82.5	65	62.9	55.6	71.4	76.5	75	12.3	72.7
Science critically examines authenticity of new evidence	75.4	82.1	78.7	77.5	70	77.1	66.7	85.7	82.4	50	10.7	76.2
Science continues to develop theories; they do not stay static or randomly change	73.1	64.2	63.8	65	50	71.4	61.1	71.4	76.5	62.5	8.4	68
8. Methods of Science												
This topic is not essential for non-majors	0.6	1.5	2.1	2.5	0	0	0	0	0	0	1	1.1
Overall, science accumulates evidence systematically and builds theories	66.5	70.1	74.5	67.5	85	65.7	66.7	78.6	88.2	62.5	8.6	69.9
Instruments increase power and accuracy of observation	52.4	47.8	51.1	47.5	40	68.6	33.3	57.1	35.3	75	13.2	50.7
"The scientific method" steps of questioning, observing, interpreting results and not reaching conclusions are standard in science	75.3	77.6	78.7	75	70	82.9	77.8	92.9	82.4	100	10.2	77.9
Observations repeated many times to ensure results are replicable	81.8	71.6	66	57.5	55	82.9	61.1	78.6	76.5	87.5	11.4	73.7
"The scientific method" is not how science works: progress made through inspiration, creativity and explainimg unexpected results	25.9	19.4	29.8	40	20	22.9	22.2	28.6	47.1	25	12	26.3
9. Experimental Design												
This topic is not essential for non-majors	6.4	9	4.3	15	0	5.7	0	0	0	12.5	17.3	6.9
Experiments must be designed in detail for reliable results	78.4	71.6	74.5	70	90	85.7	78.9	85.7	88.2	87.5	19.7	77.2
Assumptions, variables and error must be identified	58.5	56.7	55.3	55	45	65.7	52.6	57.1	52.9	37.5	8.4	56.7

TABLE 1 (cont.)

Sensitivity and specificity of tests must be considered	32.2	41.8	46.8	27.5	25	42.9	31.6	35.7	17.6	12.5	14.1	33.7
All results must be reported whether or not they support the hypothesis	84.2	83.6	72.3	80	85	85.7	73.7	92.9	82.4	87.5	14.1	81.9
Proposing multiple hypotheses is likely to produce less bias	25.1	25.4	23.4	30	25	20	36.8	21.4	29.4	37.5	10	25.2
10. Interpretation of Data, Drawing Conclusions												
This topic is not essential for non-majors	4.2	6.1	2.1	7.5	10	2.9	0	0	0	12.5	4.4	4.3
Conclusion not valid if method does not address the hypothesis	56.5	42.4	36.2	55	30	45.7	47.4	64.3	23.5	62.5	15.2	47.9
Conclusion not valid if alternative explanation of the data possible	36.3	39.4	36.2	50	35	45.7	47.4	57.1	47.1	62.5	11.7	40.2
Patterns of correlation in evidence does not prove causation	58.9	60.6	63.8	55	40	60	63.2	57.1	76.5	62.5	10.5	59.1
Investigations with negative results can be more valuable that those with positive	37.2	39.4	21.3	42.5	30	54.3	26.3	50	29.4	37.5	14.8	34.8
Science determines what part of observed change is due to chance alone	51.8	47	53.2	45	40	57.1	47.4	57.1	52.9	25	9.9	50.1
11. History of Science												
This topic is not essential for non-majors	4.2	3	6.7	10.3	5	8.6	11.1	7.1	5.9	0	3.7	5.5
The focus should be on what we know, not how we know	9.6	15.2	15.6	28.2	5	17.1	11.1	14.3	11.8	12.5	7.1	13.7
Stories of famous scientists humanize science and should be included	52.1	59.1	53.3	43.6	35	54.3	44.4	42.9	64.7	37.5	9.7	51.7
Stories of discoveries that show science to be exciting should be included	68.3	75.8	71.1	61.5	60	65.7	61.1	64.3	64.7	87.5	8.3	68.1
Episodes of non-experimental discoveries should be included	45.5	37.9	40	64.1	20	60	50	57.1	41.2	62.5	13.3	46
Original articles should be read; stories distort and falsely simplify	13.8	15.2	8.9	17.9	15	20	27.8	35.7	23.5	12.5	9.5	15.7
A complete timeline of science to show epistemology should be included	13.8	15.2	22.2	20.5	10	31.4	11.1	28.6	23.5	25	9.2	17.5
How theories were constructed, why they were superseded should be included	62.3	63.6	66.7	59	60	60	61.1	57.1	64.7	75	12.2	62.6
12. Cross Curricular Skills												
R brain dominance hinders learning science	1.2	1.5	2.2	15.4	0	5.7	5.3	0	0	0	4.7	2.9

TABLE 1 (cont.)

Science is not isolated, but an integrated part of overall education	91.2	88.1	73.9	79.5	70	85.7	73.7	69.2	94.1	100	10.3	84.9
Science is not too hard; everyone should be curious	68.8	58.2	73.9	66.7	50	77.1	57.9	69.2	88.2	62.5	13.2	66.9
Careful thinking in science should translate to any academic area	73.5	77.6	58.7	82.1	65	65.7	84.2	69.2	82.4	87.5	10.2	73.2
Writing in science needs skills from writing courses	74.1	59.7	65.2	61.5	50	80	63.2	53.8	64.7	75	9.1	67.8
Math skills help logic and problem solving skills in science and vice versa	75.3	71.6	71.7	71.8	60	77.1	73.7	69.2	82.4	100	10.9	73.6
Classroom science can be used to create plans, designs, innovations, solutions for "real world" problems	73.5	73.1	60.9	66.7	55	82.9	57.9	84.6	88.2	87.5	14.4	72.1
Science legitimately includes social sciences	44.7	48.3	47.8	48.7	35	68.6	47.4	61.5	47.1	37.5	12.8	46.8
13. Science and Society												
This topic is not essential for non-majors	1.8	0	2.2	5	0	0	0	0	0	0	1.6	1.3
Science helps make personal and family decisions concerning illness and health care	81.3	74.6	69.6	72.5	60	88.6	78.9	92.9	88.2	100	12	78.3
Scientific literacy allows people to understand news, join debate on public affairs	84.8	74.6	76.1	65	70	82.9	78.9	64.3	100	62.5	11	78.7
Science is a part of cultural heritage	60.8	59.7	58.7	50	45	68.6	78.9	85.7	64.7	75	12.9	61
Development of science and technology greatly increases a nation's prosperity	78.4	83.6	73.9	70	80	91.4	94.7	85.7	82.4	100	8.9	80.3
Interaction of science, ethics, religion should be understood	69	71.6	69.6	60	60	80	57.9	78.6	82.4	62.5	12.2	68.8
Knowledge of science helps citizens act in global issues of hunger, unsafe water supply, climate change, disease	81.9	79.1	73.9	77.5	80	88.6	57.9	100	94.1	87.5	12.9	80.3
It is not realistic for everyone to learn science, and we should focus on teaching use of technology	15.8	9	8.7	20	0	14.3	21.1	14.3	0	0	8.3	13

and the relationships amongst theories, hypotheses, and laws. These are listed in Table 3. Excluded from these less-supported topics are "The scope and limits of science," "Evidence in science vs. on the street," "Methods of science," and "Science and society."

Statements supported by occupational groups within OAS

Survey statements were subjectively divided into the broad categories of "citizens' science" (such as "Opinion without evidence is not accepted as knowledge even from famous, powerful, or popular sources," Topic 4), and "scientists' science" (such as "Sensitivity and specificity of tests must be considered," Topic 9). Forty-six statements at a more "citizens'" level, and 34 statements at a more technical "scientists'" level were identified. Percent support by OAS for these characterizations of science is seen in Figure 1, and Figure 2 shows support by occupational group. Because of the subjective division of statements, these results are only an approximation.

DISCUSSION

OAS respondents overwhelmingly rejected the idea that it is not realistic for non-majors to gain a solid enough understanding of science to influence their actions in society (Shamos' statement in Topic 13), and that a "science oriented" brain had to be inborn. The majority thought that science is not "too hard" for most people, and that all students should learn some concepts of every topic presented in the survey. This response is not unexpected from a group who work in, or are related to science; a survey of non-scientists was not performed because familiarity with science was thought necessary to make a reasoned response.

The Topics most supported in non-majors' science education were application of science in personal, social, ethical, and global issues (Topic 13), the fact that science is not a set of facts (Topic 2), and that scientific thinking is not kept for "scientific situations" only, but applies to everyday life (Topic 6); the distinction between science and pseudoscience (Topic 7); cross-curricular

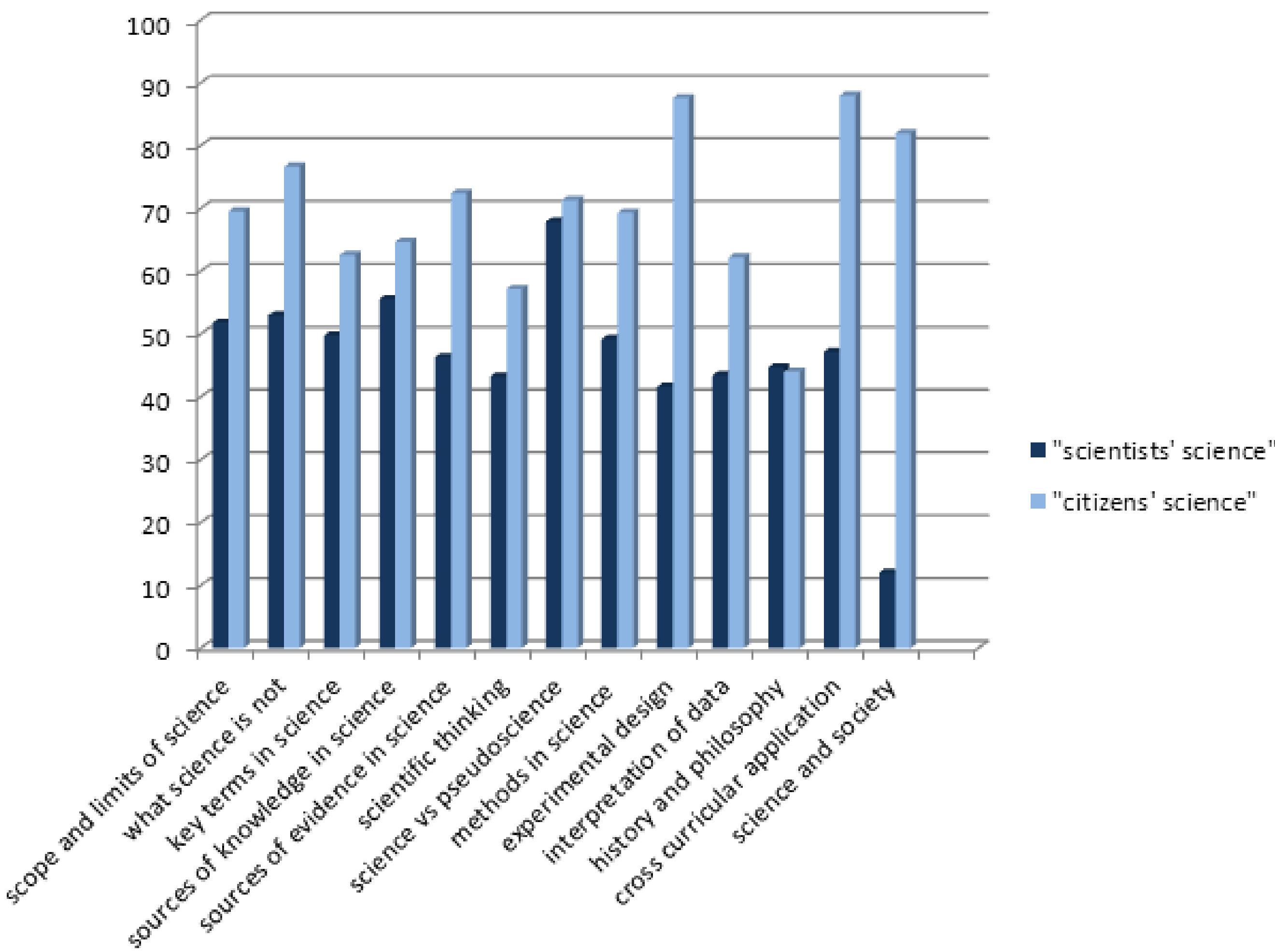


Figure 1. Percent of overall respondent support for "scientists' science" and "citizens' science" for each survey topic. Survey statements were subjectively judged to be closer to the "scientists' science" or to the "citizens' science" ends of the spectrum of scientific literacy.

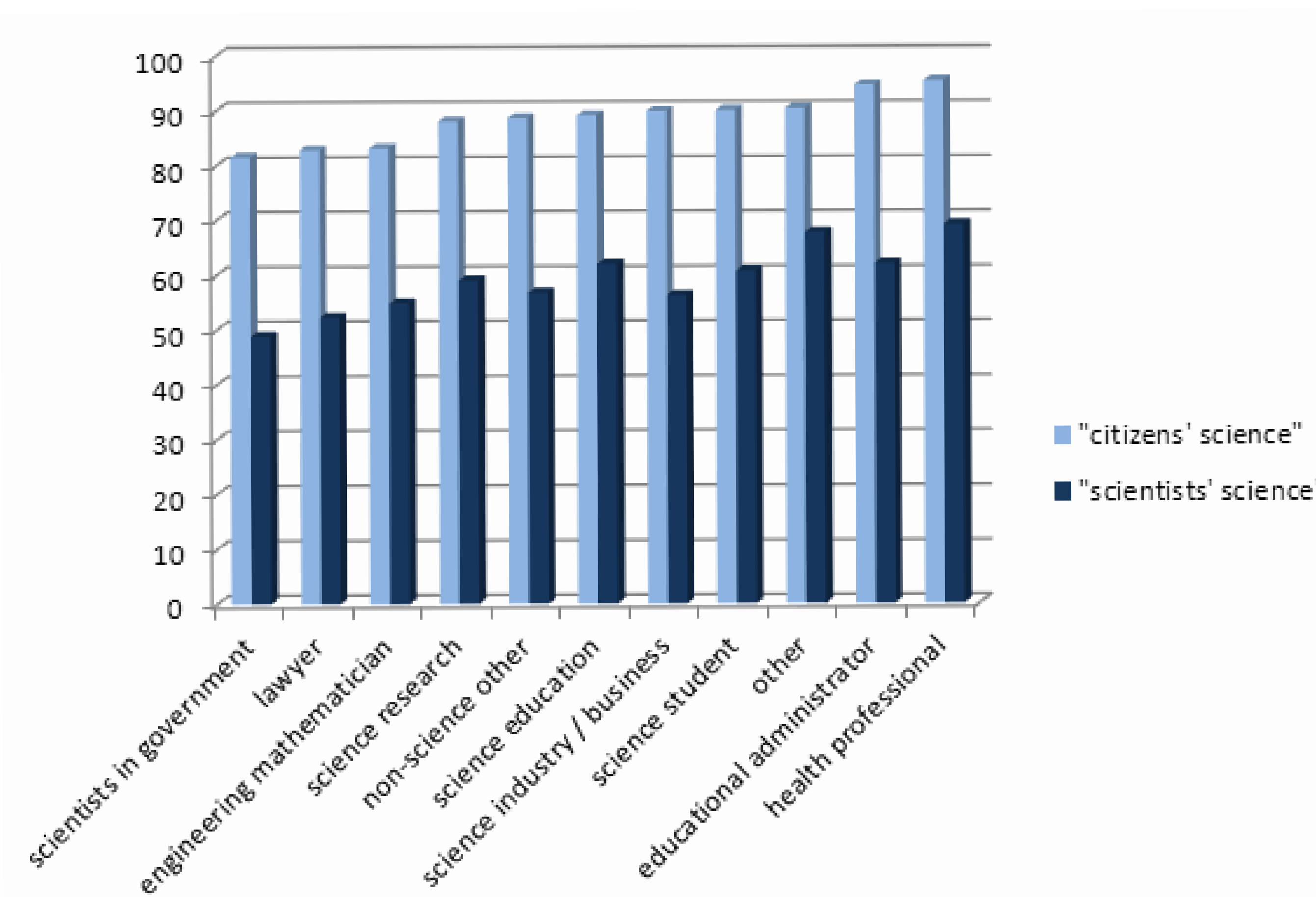
skills between science with other disciplines of study (Topic 12); and the fact that all evidence must be used rather than selected from, and that evidence is collected methodically, not randomly (Topic 5.)

It is notable that the level of knowledge selected as appropriate for non-majors was more often general and descriptive ("citizens'", or "informed outsider" science); only in one instance was a more technically specific statement selected by a greater number of respondents than a similar but more general statement (Topic 3, a definition of hypothesis more accurate than the ubiquitous "educated guess").

The lowest level of support was given to statements containing more specific information of the processes of science and the construction of knowledge, such as statements in Topic 10, Interpretation of data, drawing conclusions and in Topic 11, History of science.

Topics with medium (divided) support included a variety of issues such as statements on what is outside the scope of science (Topic 2), the tentative nature of science (Topic 1), the more elementary definitions of hypothesis theory and law (Topic 3), some parts of scientific reasoning and drawing appropriate conclusions, and subjective influences in science.

This overall profile of opinion enables students to recognize that science uses empirical evidence to construct (and reconstruct) knowledge of the natural world, to identify pseudoscience and non-scientific reasoning, and to understand that science can apply to personal, social and global problems. This corresponds more to the general non-expert "citizens' science" level termed "competent outsider", or "consumer/user", Roberts Vision II of scientific literacy rather than to "insider" or "scientists' science", Roberts' Vision I described in the introduction. However, it is not the extreme version of "citizens' science" in which science is sought for solutions to specific "scientific situations" only; the statement that this is not true (Topic 6) was supported by 80.2 percent of respondents. Additionally, for Sources of Knowledge in Science (Topic 4), and Science and Pseudoscience (Topic 7), the level of support for "scientists' science" exceeded 50 percent, and was almost as great as that for "citizen's science" (Fig. 1). Specific topics are discussed below.



Fgure 2. Percent of each occupational group supporting survey content as a whole. Survey statements were subjectively judged to be closer to the "scientists' science" or to the "citizens' science" ends of the spectrum of scientific literacy.

TABLE 2
Overall OAS support by all respondents and SD of occupational group means for the 25 survey statements most favored (> 70 percent overall) for inclusion in non-majors' education

Topic Group	Survey Statement	Overall percent support	SD from overall mean
1	Science is a way of understanding the natural world (universe)	90.3	4.5
12	Science is not isolated, but an integrated part of a person's overall education	84.9	10.3
2	Science is not a set of facts, but a process of exploration and explanation	84.2	8.7
5	Evidence is obtained by systematic observation/testing/measurement, not randomly	83	5.3
9	All results must be reported whether or not they support the hypothesis	81.9	14.1
13	Development of science, technology greatly increase a nation's strength and prosperity	80.3	8.9
13	Knowing science enables citizens to contribute to global issues: feeding world's population, ensuring adequate water supplies, managing climate change, eradicating disease	80.3	12.9
6	Thinking scientifically is not just for scientific situations but applies to everyday life	80.2	15.2
4	Opinion without evidence is not accepted as knowledge, even if from famous, revered or powerful sources, or however many people voice it	79	9.1
13	Scientific literacy allows individuals to understand news, join in debate on public affairs	78.7	11
13	Scientific literacy helps make personal and family decisions concerning health care	78.3	12
8	"The scientific method" steps of questioning, observing, interpreting results and reaching conclusions is standard in science	77.9	10.2
5	All evidence must be weighed; it cannot be selected or ignored to suit a particular viewpoint	77.2	12.9
9	Experiments must be designed in careful detail to give accurate results	77.2	19.7
7	Science critically examines the authenticity of new evidence; it does not take it for granted	76.2	10.7
7	Knowledge and methods in science are openly published, not kept as mysterious secrets	75.8	14.4

TABLE 2 (cont.)
Overall OAS support by all respondents and SD of occupational group means for the 25 survey statements most favored (> 70 percent overall) for inclusion in non-majors' education

Topic Group	Survey Statement	Overall percent support	SD from overall mean
5	Arguments are supported by providing adequate, relevant evidence, not by passionate appeal	75	9.7
8	Observations are repeated many times to make sure the results are replicatable	73.7	11.4
12	Math skills definitely help logic and problem solving skills in science, and vice versa	73.6	10.9
3	Theories change with new evidence; this strengthens, not weakens them	73.3	13.2
12	The careful thinking in science should be transferred to any academic subject to help organize thoughts	73.2	10.2
7	Science seeks to explain new findings in the light of previous knowledge; it does not ignore it		12.3
13	Science from the classroom can be used to to create plans, designs, innovations and solutions for issues in the "real world"	72.1	14.4
6	A questioning and skeptical attitude is fundamental to science	71	8.1
3	A hypothesis is a proposed, researched, testable explanation for a particular phenomenon	70.6	5.5

The scientific method

The survey offered statements related to both the simple step-wise scientific method and a statement reflecting a more complex reality. Respondents greatly favored the simple version as essential for non-majors (mean of scientists 75.3 percent, mean of non-scientists, educational administrators, health professionals and lawyers 93.8 percent), but their comments clarify that while the simple method can be a starting guide, in reality practicing scientists do not follow a rigid sequence, but instead use scientific habits of mind in more flexible and adaptive ways. Also noted by respondents is that other disciplines use the patterns of critical observation and logical thinking of science, which cannot then be termed "scientific." In fact, the boundaries of what is scientific and what is not remain undefined in philosophy (Rudolph 2003).

A fixed "method" does not apply because testing is not always available (as in geology, astronomy), practices vary widely amongst specialties in science, and progress made through chance or inspiration is legendary. Interviews with scientists indicate that many do not perform experiments, do not follow a step-wise procedure, and do not always posit hypotheses, but go on "fishing expeditions" in which technology allows the generation of vast amounts of data that can be "mined" after collection (Wong and Hodson 2008).

A Framework for K-12 Science Education (NRC 2011) strongly emphasizes teaching practices such as planning and carrying out investigations, developing and using models, and using argumentation from evidence rather than a single, linear "method", and yet the simple version is almost universal. Of the first 100 "hits" of the 22 x 10^6 returned by an internet search for "the scientific method" over 90 percent--even those intended for a university audience--present a linear sequence of steps from question to conclusion. Studies of introductory science textbooks have shown the same pattern (Abd-El-Khalik and others 2008, Blachowicz 2009).

Theory, hypothesis, law

Alone in the survey, the more realistically scientific statements in Key Terms in Science (Topic 3) received greater support than the simple ones. "A hypothesis is a proposed, researched, testable explanation for a particular phenomenon" was favored (70 percent) over the "educated guess" (59.1 percent) found throughout educational websites and texts. Similarly the more scientific definition of law as "as statement of relationship seen to hold true" was favored (62.4 percent) over the simpler "rule but not an explanation" (49.3 percent). "The method of science is to accumulate evidence by systematic investigation and to build theories from it" received support from 69.9 percent of respondents.

Although the word "tentative" was thought misleading for non-majors by two respondents, several others commented on the importance of understanding why and how science appears to overturn ideas over time. The survey statement "Theories change with new evidence; this strengthens, not weakens them" received 73.3 percent support, but understanding the relationship amongst hypothesis, theory, and law was thought not to be essential (around 25 percent support).

Theory, hypothesis, and law are fundamental to science, but as respondents commented, that the terms are confused by students and sometimes used carelessly by scientists. According to McComas, misunderstanding of their meaning and inter-relationship is common. (McComas 1996).

Scientific thinking

OAS respondents were strongly in favor of teaching science as thinking and explaining rather than as facts (84 percent) (Topic 2) and the notions that "scientific thinking should be used in everyday life" and "a questioning and skeptical attitude is fundamental to science" (both Topic 6) were also well supported (80.2 percent and 71 percent). The survey statement, "the focus should be on what we know rather than how we know" (Topic 11) was favored by only 13.7 percent of respondents, reflecting the importance of the construction of scientific knowledge.

In 1903 John Dewey criticized "...learning in the sense of becoming possessed of the second-hand and ready-made material" (Dewey 1903), but by 2009 the Editor-in-Chief of *Science* still found it "a disturbing situation" that science is still often taught as facts rather than as thinking (Alberts 2009). The reason "science as facts" instruction persists has been attributed to time constraints, class size, student ability and motivation, and instructors' negative views of classroom inquiry and other constructivist methods (Brown and others 2006).

Although OAS support was minor (around 42 percent) for teaching the notion that scientific thinking is not purely objective, but can be influenced by subjective factors, many respondents commented that thinking in "real world" science is indeed subjectively influenced by many factors including ethical, social, personal and political issues, by bias toward favored hypotheses or preconceived notions, and especially by the system of funding.

The interrelatedness of "human-ness" and science is interesting. That "scientists are human" was an OAS respondent comment accounting for loss of objectivity in science, but on the other hand, scientific thought, considered a transcendent human achievement (Wightman 2011), in turn allows us to understand what it is to be human (Dunbar and Fugelsang 2005), or as another respondent noted, "Science tells us who we are."

Use of evidence

Nine of the 25 most widely supported (> 70 percent) survey statements referred to gathering evidence, evaluating evidence, using all (not selected) evidence, distinguishing between opinions of public or powerful persons and evidence, or between passionate appeal and evidence (Table 2). The statement that science is different from religion as it is based on evidence gained 68 percent support for inclusion in non-majors' education. Several OAS respondents commented that understanding scientific thinking enables students to recognize subjective and distorted use of evidence in media reporting, a theme also raised in *Science:* "Vast numbers of adults fail to take the scientific approach to solving problems or making judgments based on evidence. Instead they readily accept simplistic answers to complicated problems that are confidently espoused by popular talk-show hosts or political leaders, counter to all evidence and logic" (Alberts 2009).

Science vs. pseudoscience

Survey statements concerning pseudoscience (Topic 7) refer to the peer-reviewed (not secret) nature of scientific information, the continuing examination and

TABLE 3
Overall OAS support by all respondents and SD of occupation group means for the 20 survey statements least favored (< 50 percent overall) for inclusion in non-major's education (excluding negative statements)

Topic Group	Survey Statement	Overall percent support	SD from overall mean
11	The focus shoul be on what we know, not how we know	13.7	7.1
11	Stories distort; original papers should be read	15.7	9.5
11	A timeline for epistemology should be included	17.5	9.2
3	A hypothesis does not become a theory	24.4	8.7
3	A theory does not become a law	25.7	8.4
9	Multiple hypotheses produce less bias	25.2	10
6	Reasoning is inductive or hypothetico-deductive	29	15.1
9	Sensitivity and specificity of tests must be considered	33.7	14.1
10	Negative results can be more valuable than positive	34.8	14.8
5	Falsification has more impact than verification	39.3	7.4
6	Social and spiritual value play no part	39.4	9.6
10	Conclusion not valid if alternative explanation possible	40.2	11.7
6	Relevance and importance of ideas are identified	41.6	9.6
4	Theories tend to be normative until revolutionized	42.8	10.6
6	Scientists are influenced by social and academic factors	45.2	9.5
12	Science legitimately includes social sciences	46.8	12.3
2	Science is not the same as technology	47.2	4.8
10	Conclusion not valid if method does not test hypothesis	47.9	15.2
2	Science cannot produce moral or ethical solutions	48.2	7.8
3	A law is a rule but not an explanation	49.3	14

development of theories, and the scrutiny of evidence for authenticity. In common with other statements on the use of evidence these were among the most strongly supported statements (> 70 percent) in the survey. However, the more detailed reasoning for drawing conclusions (e.g. concerning chance, correlation/causation, and alternative explanations) gained 50-60 percent of support, and the significance of negative results had only 30 percent support.

The ability to recognize pseudoscience is greatly needed: Science and Engineering Indicators 2010 (an annual NSF publication of quantitative data) reports belief in astrology among the US population unchanged over the last 30 years, and popular culture abounds with pseudoscience concerning issues such as health and weight loss.

History of science

Teaching historical stories gained 68.1 percent support from OAS respondents, although some comments were added that, while history is an important topic for understanding science as more than a body of knowledge, it is time consuming, and using both samples of stories and primary literature was suggested.

The history of science can illustrate its (multi)cultural origins and humanistic aspects, counteract dogmatism, and show science as it is really practiced (Galili and Hazan 2001, Kolstφ 2008). The nature of science can be demonstrated through anecdotes: vignettes of Galileo show its empirical and predictive nature; the "cold fusion" story brings out its tentative and self-correcting qualities; the development of nuclear weapons illustrates political influence on its direction (McComas 2008). Science-related popular non-fiction (such as *Galileo's Daughter*) has also been used to connect students to science (Straits and others 2011).

However, stories have been criticized as misleading if they idealize events by framing in contemporary terms (Monk and Osborne 1997), promote "the present as the inevitable triumphant product of the past" (Brush 1974), or hide the man-made, puzzling and serendipitous aspects of science. Allchin illustrates how retrospective reconstruction of events generates "pseudo-history" or myth; for example Harvey's work on blood circulation is often arranged to exemplify a simple hypothetico-deductive process that did not take place (Allchin 2004).

Constructivist models have been described that avoid the "added" use of stories to "humanize" science by placing historical materials at the center of the curriculum, and using them to step through the processes of discovery and the construction of knowledge (its epistemology) (Monk and Osborne 1997). The survey statement (Topic 11) that non-majors should understand the epistemology of science had little support, (17.5 percent); however, the statement that "past theories should be studied, why they were constructed and superseded" was better supported (62.6 percent).

Science in society

The application of science in everyday life or in solving global problems such as hunger and preventable disease made up 10 percent of the 95 survey statements (Topic 13), but figured as 20 percent of the 25 best supported statements in the survey (Table 2). According to AAAS, the future depends on better understanding of science by liberally educated citizens (AAAS 1990); with this idea a respondent commented, "Most individuals… may not be able to directly contribute to solving the problems, however a comprehension of why the problems exist can lead to public support." Teaching about this topic can be problematic as the syllabus is often planned around, or "dominated" by the textbook (Alles 2004), but textbooks give brief space to social applications of science (Hodson 2009). Also, there is a disconnect between the classroom and the real world; inside the classroom students do not find relevance to their own lives in the usual "transmissive" style of teaching science (Lyons 2006), but once students are outside the classroom whatever skills and knowledge have been learned there do not readily transfer because learning is contextual (Naughton and others 2008). OAS respondents strongly supported cross-curricular transfer and integration of learning for general application, but this topic more than any other in the survey might constitute a challenge for instructors, and call for thoughtful pedagogy. As a respondent commented, "We need to do a better job of connecting to their world."

Conclusion

The purpose of the survey was to discover what scientists and those interested in science in Ohio consider 1) which topics of science (other than discipline-specific content), and 2) what level of complexity, are essential for non-major students to learn about science in their brief college science education. OAS respondents almost unanimously agreed that all students can and should learn some parts of all topics presented in the survey. Although some content concerning the generation of scientific knowledge was supported, the level selected was most often elementary (not "scientists' science"), including the simple version of scientific method. An exception to this was that the more complex versions of definitions of hypothesis, theory and law were favored more than the simpler versions.

The most strongly supported content concerned the origins and use of evidence in science contrasted with "everyday" thinking and pseudoscience, and the interdependence of scientific habits of mind with other academic disciplines. Additionally, content concerning applications of science and scientific thought to real world problems made up only 10 percent of the survey, but constituted 20 percent of all statements that gained more than 70 percent support overall.

Although some bias might be expected in opinions of scientists on what science should be taught, the general, non-expert level "competent outsider" or "consumer/user" profile of scientific literacy recommended by OAS respondents for non-science majors is clearly different from their own type of literacy. This was emphasized by the many comments recognizing that the reality of science is not clear-cut, that almost any characterization (science is objective, scientific knowledge is reliable, original papers are a truer representation of science than stories, science is common sense codified, scientific information is openly published) is debatable at some level, and especially that the ordered steps of the "scientific method" are at variance with how scientists actually proceed.

The survey results have pedagogical implications because topics that survey respondents believe to be essential to non-majors (e.g. the nature and use of evidence and the application of science to social and global issues) are often not represented in textbooks (Hodson 2009); therefore, instructors should consider developing or finding their own curricular materials. Additionally, if students are preparing to be "competent outsiders" with "citizen's science" they will need to be taught how to recognize relevant and trustworthy sources of expertise, a skill that is not easy to acquire (Norris and Phillips 2003; Solomon and Thomas 1999). Lastly, scientific literacy includes the ability to act in science-related issues in society, and to do this students will need to understand connections between knowledge gained in the classroom and knowledge needed in the real world.

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