The Public Understanding of Science in Europe and the United States

Jon D. Miller

John A. Hannah Professor of Integrative Studies
and
Director of the International Center for the Advancement of Scientific Literacy
Michigan State University
East Lansing, Michigan
jdmiller@msu.edu

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One of the few issues that the leaders of the European Union and the United States agree on without reservation is that scientific literacy is a good thing and that having more of it would benefit our respective societies. In Europe and the United States, educational leaders and institutions focus substantial resources and organizational energy on the promotion of scientific literacy in student populations, sharing an assumption that the successful teaching of science and mathematics in the classroom will prepare students to function as scientifically literate citizens for the rest of their lives.

Over the last 30 years, a series of international studies have focused on student achievement in science and mathematics. The results have shown that Asian students are generally superior to both European and American students and that European students are significantly more advanced in science and mathematics than American students at every grade level (Schmidt, McKnight & Raizen, 1997). On the basis of these results, it would be expected that European adults would be significantly more likely to be scientifically literate that Americans.

Last year, a cross-national comparison of the acceptance of biological evolution by adults in 34 countries found that Americans ranked 33rd in their acceptance of evolution, followed only by Turkey (Miller, Scott & Okamoto, 2006). Can there be any doubt that Americans are among the least scientifically literate adults in any modern industrial nation?

In the spirit of the annual meeting of the American Association for the Advancement of Science, it is appropriate to look at the data before rendering a final judgment on this question. This paper will (1) define civic scientific literacy, (2) discuss its measurement in the United States and Europe, and (3) examine the results for 34 countries, and (4) discuss the implications of the results for education policy, science policy, and democratic government in the 21st century.

The Concept of Civic Scientific Literacy

To understand the concept of civic scientific literacy, it is necessary to begin with an understanding of the concept of *literacy* itself. The basic idea of literacy is to define a minimum level of reading and writing skills that an individual must have to participate in written communication. Historically, an individual was thought of as literate if he or she could read and write their own name. In recent decades, there has been a redefinition of basic literacy skills to include the ability to read a bus schedule, a loan agreement, or the instructions on a bottle of medicine. Adult educators often use the term "functional literacy" to refer to this new definition of the minimal skills needed to function in a contemporary industrial society (Kaestle, 1985; Cook, 1977; Resnick and Resnick, 1977; Harman, 1970). The social science and educational literature indicates that about a quarter of Americans are not "functionally literate," and there is good reason to expect that roughly this proportion applies in most mature industrial nations and a slightly higher rate in emerging industrial nations (Ahmann, 1975; Cevero, 1985; Guthrie and Kirsch, 1984; Northcutt, 1975).

In this context, civic scientific literacy is conceptualized as the level of understanding of science and technology needed to function as citizens in a modern industrial society (Shen, 1975; Miller, 1983a, 1983b, 1987, 1995, 1998). This conceptualization of scientific literacy does not imply an ideal level of understanding, but rather a minimal threshold level. It is neither a measure of job-related skills nor an index of economic competitiveness in a global economy.

The initial measurements of scientific literacy in the 1980's and 1990's found evidence of two dimensions -- a basic vocabulary of scientific terms and concepts and an understanding of the process or methods of science for testing our models of reality (Miller, 1983b, 1987, 1995, 1998; Durant, Evans, and Thomas, 1989, 1992; Evans and Durant, 1995). An important point of difference in the literature has been how to combine these two dimensions into a single index of scientific literacy. To a large extent, this issue has resolved itself. National surveys of adults in the United States show that the distinction originally found between the two factors in studies in the mid-1980's narrowed over the remaining years of the 20th century. Recent national surveys in Europe and the United States – reported below in greater detail – indicate that the vocabulary and process dimensions have become empirically inseparable. It appears that this pattern reflects a real change in the patterns of adult understanding of science in both Europe and the United States and is not a measurement artifact.

The Measurement of Civic Scientific Literacy

In developing a measure of civic scientific literacy, it is important to construct a measure that will be useful over a period of years and that will be sufficiently sensitive to capture changes in the structure and composition of public understanding. If a time series indicator is revised too often or without consciously designed linkages, it may be impossible to separate the variation attributable to measurement changes from real change over time. The periodic debates over the composition of consumer price indices in the United States and other major industrial nations are a reminder of the importance of stable indicators over periods of time.

The durability problem can be seen in the early efforts to develop measures of the public understanding of science in the United States. In 1957, the National Association of Science Writers (NASW) commissioned a national survey of public understanding of and attitudes toward science and technology (Davis, 1958). Since the interviewing for the 1957 study was completed only a few months prior to the launch of Sputnik I, it is the only measure of public understanding and attitudes prior to the beginning of the space race. Unfortunately, the four major items of substantive knowledge were (1) radioactive fallout, (2) fluoridation in drinking water, (3) polio vaccine, and (4) space satellites. Fifty years later, at least three of these terms are no longer central to the measurement of public understanding.

Recognizing this problem, Miller attempted to identify a set of basic constructs, such as atomic structure or DNA, that are the intellectual foundation for reading and understanding contemporary issues, but which will have a longer durability than specific terms, such as the fallout of strontium 90 from atmospheric testing. In the late 1970's and the early 1980's, when the National Science Foundation began to support comprehensive national surveys of public understanding and attitudes in the United States, there was little experience beyond the 1957 NASW study in the measurement of adult understanding of scientific concepts. The first U.S. studies relied heavily on each respondent's self assessment of their level of understanding of various terms and concepts, building on a survey research literature that suggested that when respondents are offered a trichotomous set of choices -- i.e., do you have a clear understanding of [construct A], a general sense of [construct A], or not much understanding of [concept A] -- individuals selecting the clear understanding choice would be very likely to understand the concept, while individuals who were unsure about the concept or who did not understand it might select the middle or lower category (Converse and Schuman, 1984; Sudman and Bradburn, 1982; Labaw, 1980; Dillman, 1978; Oppenheim, 1966). The basic idea was that respondent inflation of their knowledge would occur primarily between the little understanding and general sense categories. This approach is still used in national studies in some countries and can provide useful estimates, but at a lower level of precision than provided by direct substantive inquiries.

In a 1988 collaboration between Miller in the U.S. and Thomas and Durant in the U.K., an expanded set of knowledge items was developed that asked respondents direct questions about scientific concepts. In the 1988 studies, a combination of open-ended and closed-ended items were constructed that provided significantly better estimates of public understanding than had been collected in any prior national study. From this collaboration, a core set of knowledge items emerged that have been used in studies in Canada, China, Japan, Korea, India, New Zealand, and all 27 members of the European Union.

To a large extent, these core items have provided a durable set of measures of a vocabulary of scientific constructs, but it is important to continually enrich the mix to reflect the growth of science and technology. For example, Miller's 2003, 2004, and 2005 studies of the American public have included new open-ended measures of stem cell, nanotechnology, neuron, genomic, and neuroscience and new closed-ended knowledge items concerning the genetic modification of plants and animals, nanotechnology, ecology, and infectious diseases. Through the use of Item-Response-Theory (IRT), it is possible to incorporate marginal changes in the composition of a set of items and to produce comparable total scores (Zimowski et.al., 1996).

An examination of the factor loadings in the 2005 U.S. study illustrates the unidimensional nature of the construct (see Table 1). There is a mix of construct vocabulary questions and process-oriented questions throughout the distribution of loadings. Open-ended items tend to have slightly higher loadings than closed-ended questions because they have a lower guessing component and provide a more accurate indicator of knowledge or understanding. Open-ended items, however, are more costly to collect and code and often create more resistance from respondents. A mixture of closed-ended and open-ended questions provides the optimal solution to the measurement of respondent knowledge. This confirmatory factor analysis demonstrates that all 31 of these items reflect a common factor.

The Calibration and Computation of Individual Scores

As noted above, confirmatory factor analyses document the existence of a set of diverse science knowledge items that load on a single scale. To set the 2005 results from Europe and the United States in the context of previous studies, the responses from the 2005 studies were added to an IRT database that includes responses from previous U.S. national studies conducted in 1988, 1990, 1995, 1997, 1999, 2001 and 2004; Eurobarometers from 1992 and 2001; and a 2001 national study in Japan. This multi-year IRT model includes more than 75,000 respondents.

By computing a difficulty estimate, an efficiency estimate, and a guessing parameter, the IRT technology can calibrate each of these items on a common metric over the full range of items, groups, and years and use various combinations of items to compute a total score for any individual in any of the groups in any year (Zimowski et.al., 1996). The IRT scoring procedure produces a standardized score with a mean of zero and a standard deviation of 1.0. For reporting purposes, the mean (computed

Table 1: Confirmatory Factor Analysis of Science Knowledge Items, 2005.

	Loading
Provide a correct open-ended definition of a “stem cell.”	.84
Provide a correct open-ended definition of a “molecule.”	.80
Disagree: “A nanometer is equal to 1/100th of an inch.”	.77
Provide a correct open-ended definition of a “neuron.”	.76
Disagree: “Lasers work by focusing sound waves.”	.76
Provide a correct open-ended definition of “DNA.”	.75
Disagree: “Ordinary tomatoes … do not have genes but genetically modified tomatoes do.”	.73
Disagree: “Stem cells occur only in plants.”	.73
Disagree: “Antibiotics kills viruses as well as bacteria”	.69
Disagree: “Nuclear power plants destroy the ozone layer.”	.68
Provide a correct open-ended definition of “what it means to study something scientifically.”	.67
Agree: “Electrons are smaller than atoms.”	.67
Disagree: “Global warming is increasing primarily because the level of direct radiation from the Sun is increasing.”	.65
Agree: “The center of the Earth is very hot.”	.65
Agree: "The continents on which we live have been moving their location for millions of years and will continue to move in the future"	.61
Provide a correct open-ended definition of an “experiment.”	.61
Agree: “More than half of human genes are identical to those of mice.”	.60
Disagree: “For the first time in recorded history, some species of plants and animals are dying out and becoming extinct.”	.59
Indicate that the Earth goes around the Sun once each year through two closed-ended questions.	.58
Indicate that light travels faster than sound	.57
Disagree: "The earliest humans lived at the same time as the dinosaurs"	.56
Agree: “Over periods of millions of years, some species of plants and animals adjust and survive while other species die and become extinct.”	.56
Agree: “All plants and animals have DNA.”	.54
Agree that astrology is not at all scientific.	.52
Disagree: “Humans have somewhat less than half of their DNA in common with chimpanzees.”	.50
Agree: “The universe began with a huge explosion.”	.49
Agree: “The greenhouse effect causes the Earth's temperature to rise.”	.48
Agree: “The primary human activity that causes global warming is the burning of fossil fuels such as coal and oil.”	.47
Indicate a correct understanding of the meaning of the probability of one in four.	.44
Agree: “One of the effects of global warming will be that some species of plants and animals will thrive and other species will become extinct.”	.41
Agree: “Human beings, as we know them today, developed from earlier species of animals.”	.37
Chi-squares = 9580; degrees of freedom = 456; Root Mean Square Error of Approximation (RMSEA) = .040; 90% confidence interval for RMSEA= .038, .043.	

over the full database) was set to 50 with a standard deviation of 20. In terms of individual scores on the Index of Civic Scientific Literacy, the resulting scores range from approximately zero to 100.

A score of 70 or higher is indicative of a level of understanding sufficient to understand science and technology stories in the *New York Times* Science Times section or in *Science et Vie*. Like all threshold measures, the cut point is somewhat arbitrary. It is only somewhat arbitrary because it is clear from an examination of the items that respondents are able to answer correctly that individuals with a score below the middle 60's would have a very difficult time making sense of the current debates over global climate change or embryonic stem cells. If the cut point were to be moved up or down two or three points, the basic conclusions that one would draw from this work would not change.

Using this threshold measure of civic scientific literacy, the results show a steady and significant improvement in the score of American adults over the last 18 years, in sharp contrast to the performance of American secondary school students. The proportion of American adults who are able to score 70 or higher in this Index grew from 10% in 1988 to 28% in 2005 (see Figure 1).

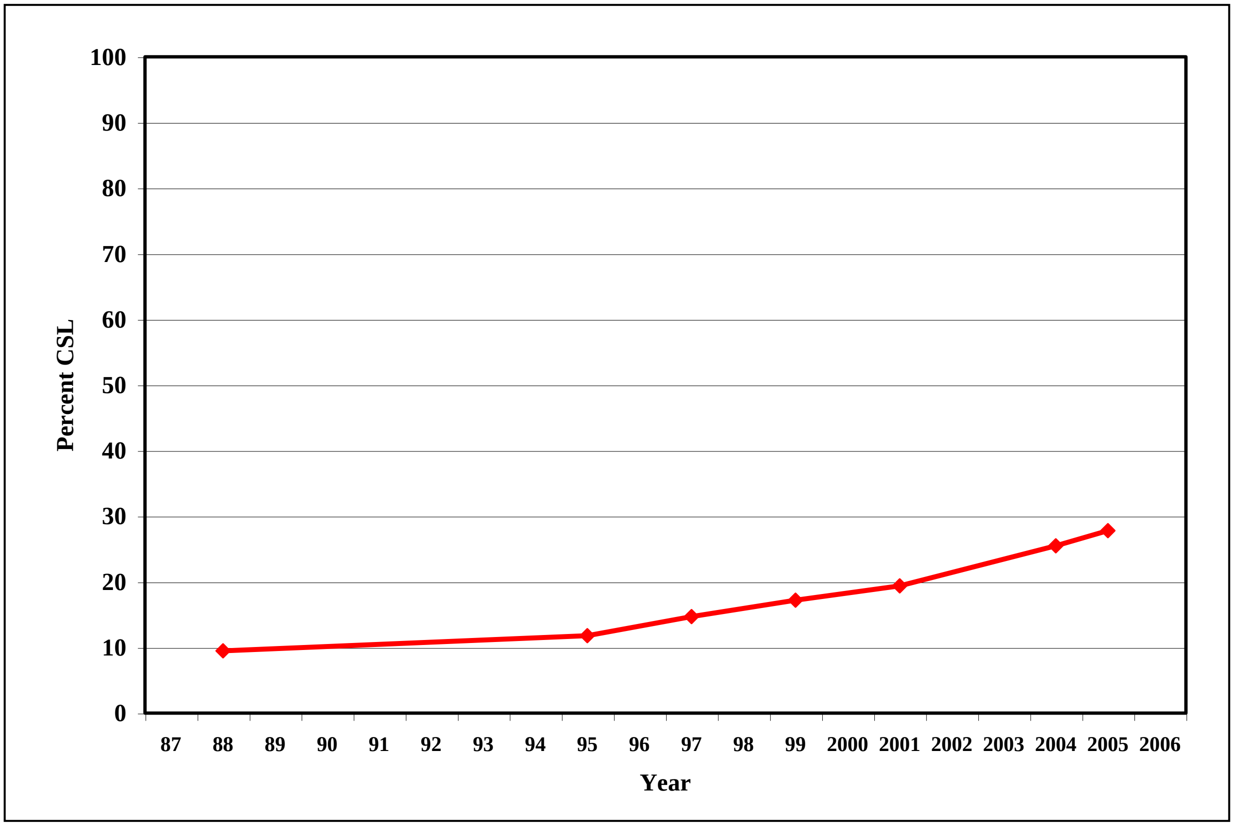

Figure 1: Civic Scientific Literacy in the United States, 1988-2005.

Turning to the principal focus of this analysis, twice as many American adults qualify as scientifically literate as do adults in the European Union (see Figure 2). Using a common metric, 28% of American adults and 14% of European Union adults scored 70 or higher on the Index of Civic Scientific Literacy and may be termed scientifically literate. This result is consistent with earlier analyses of the European Union (then 15 members), Canada, Japan, and the U.S. in the early 1990's (Miller, Pardo & Niwa, 1997). Japan ranked last among the four national groups compared in the earlier analysis[1].

Viewed in terms of individual countries, American adults rank second to only Sweden among the 34 countries from which current data area available, using the same metric and the same cutting point. In 2005, approximately 35% of Swedish adults qualified as civic scientifically literate, significantly higher than the 28% of American adults who qualified as scientifically literate (see Figure 2). On the same metric, 24% of Dutch adults and 22% of adults in Norway, Finland, and Denmark were classified as civic scientific literate. In any ranking of this kind, differences of two or three percentage points do not reflect statistically significant differences.

Discussion

Given the poor performance of American secondary students and the low level of adult acceptance of biological evolution by American adults, how can this result be correct?

First, it is not a statistical artifact or error. The measurement methods were described in detail in the preceding sections of this paper to document that the 31 items asked of American adults are a fairly rigorous cross-section of modern science. Although the adults in the 2005 Eurobarometer were asked only 12 knowledge questions, the Eurobarometer items were a good cross-section of the total item pool and the IRT technology described above took into account the relative difficulty of the items in computing the civic scientific literacy score (Zimowski et.al., 1996).

Second, the equalizer in science education is the unique American requirement that all college and university students take at least one year of college science courses en route to a baccalaureate. Although the uniqueness of this requirement is not widely recognized or appreciated in the United States, it appears to be the major factor in fostering civic scientific literacy among American adults. In other work reported at this meeting, Miller (2007) has demonstrated that college science courses give non-science majors a sufficient understanding of a basic set of scientific constructs and that these basic constructs are the necessary tools for adults to read and make sense of emerging news about science and technology. By 2005, one in three American adults reports that they had enrolled in a college science course at some time in their life.

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[1] A full discussion of the Japanese results is beyond the scope of this paper. It will be addressed in more detail in a separate paper being prepared in cooperation with Japanese scholars, but it is important to note the surprisingly low rate of civic scientific literacy in Japan in their most recent national study in 2001. Although a similar result was found in analyses of data from 1991, the finding that only 5% of Japanese adults qualify as scientifically literate in 2001 stands in sharp contrast to the outstanding performance of Japanese students on comparative international tests. The major explanation appears to be that Japanese students focus on their science courses during high school in order to score high on the university admissions examination, but do not retain the information once they have finished secondary school. Like European students, Japanese college students are not required to take science courses unless they are majoring in a field that requires scientific skills or understanding.

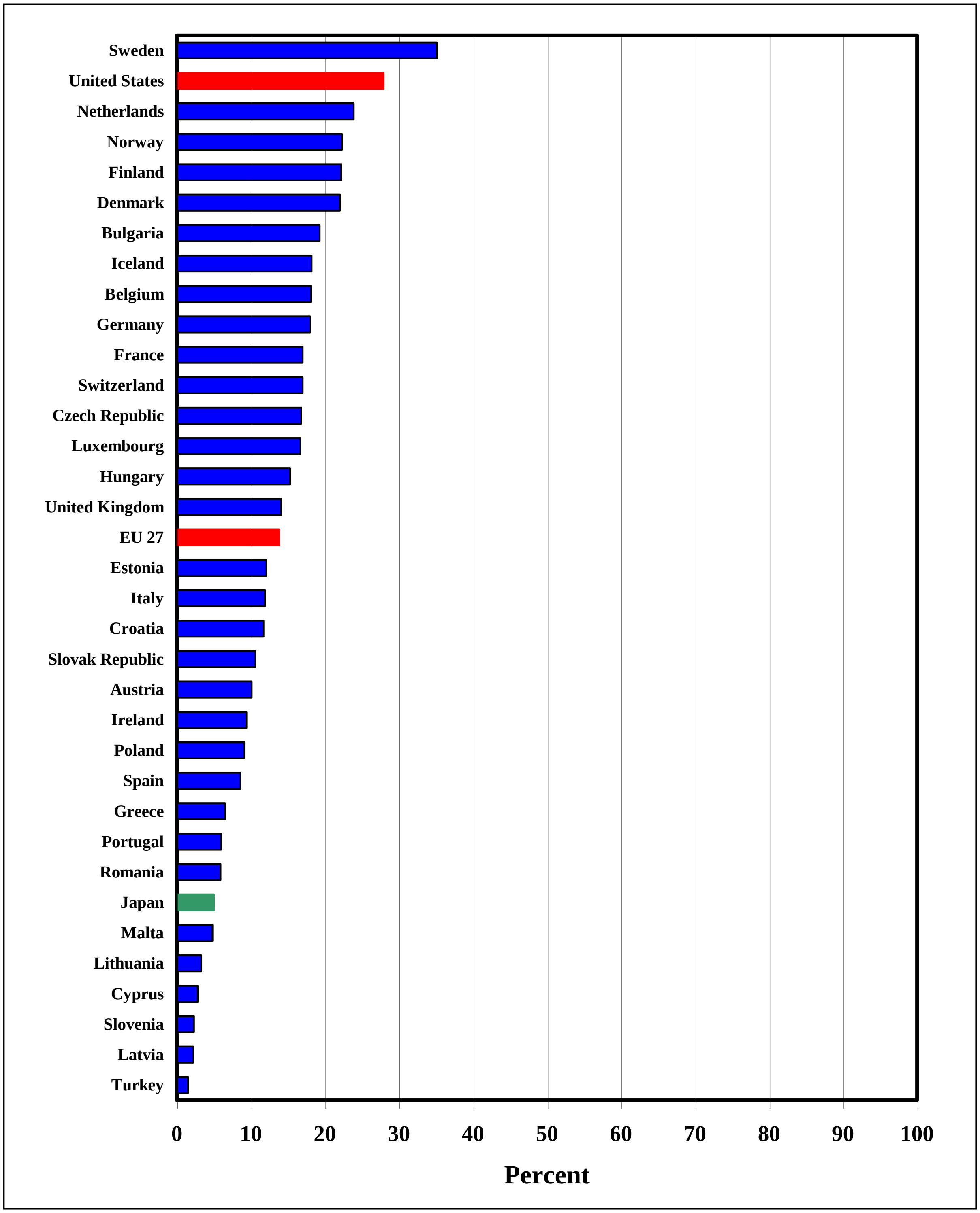

Figure 2: Civic Scientific Literacy in 34 Countries, 2005.

Third, over the last two or three decades, the resources available for American adults to learn about science and technology have expanded in scope and quality. The Tuesday science section of the *New York Times* is widely read and even more widely syndicated to other newspapers in the U.S. and other countries. Many science museums and centers have traded in their glass cases for newer interactive learning opportunities and core television science shows – primarily *Nova* – have continued to be available. Most importantly, approximately 75% of American households now have Internet access and studies show that nearly half of American adults report that they have used the Web to look for health or science information. The combination of the availability of these science learning resources and the growing proportion of American adults who have experienced one or more college science courses appears to have produced a significant increase in the proportion of American adults able to qualify as scientifically literate (see Figure 1).

This pattern fits into our general sense of educational impact. A large proportion of individuals who have completed one or more college science courses will have acquired some understanding of a set of basic science constructs. They should know more about the nature and structure of matter, for example, than adults who have never taken a college science course. Similarly, adults who have had one or more college biology courses should know more about the nature and structure of life – cells, DNA, and natural selection – than adults who have never experienced those courses. An understanding of these basic constructs might be expected to both encourage the use of informal science learning resources – books, museums, aquariums, planetariums, and the Internet – and to make that use more effective. When new constructs such as stem cells or nanotechnology enter the popular media and public discourse, adults who have had college science courses will already have a larger array of scientific constructs in their mind than other adults and they will be able to use those previously acquired constructs to make sense of the new concept more rapidly than adults who lack those constructs.

Fourth, the high proportion of American adults who reject the concept of biological evolution is a joint failure of our secondary education system and the emerging structure of partisanship in the United States. In the second half of the 20th century American political parties began to polarize into a liberal-conservative division. The civil rights movement forced the Democratic Party to expel its southern racist wing, and the Republican Party – following Nixon's "southern strategy" – embraced the former Democrats. The resulting re-alignment was further polarized by the decades-long fight over abortion rights and the labels "pro-life" and "pro-choice" reflect the depth of that division. In the last two decades, a national coalition of religious fundamentalists – mostly Protestant -- has become politically active and has largely captured the Republican Party (Danforth, 2006). By the end of the 20th century, it was possible to identify a set of states that almost always voted Republican and another set of states that almost always voted Democratic – referred to as the red states and the blue states respectively. The nearly equal division of American voters in the 2000 and the 2004 presidential elections has both crystallized and deepened this partisan division.

The emerging conservative coalition has used the rejection of evolution as a litmus test for genuine conservativism. The evolution issue has been effective in defeating moderate candidates in Republican primary elections and this process has produced a more uniformly conservative Republican Party than at any time in its long history. In the 2004 presidential election and the 2006 congressional elections, the stem cell issue was used as one of the rallying cries for conservative Republicans, and Mooney (2005) has characterized these actions as the "Republican war on science."

In Europe, the only comparable political attack on science has come from the Green Party and that attack has been focused primarily on genetic modification issues and nuclear power. As other papers in this symposium will demonstrate, there are religious groups in Europe who reject the concept of biological evolution, but they have yet to gain broad political footing comparable to the Republican Party in the United States.

On balance, European adults are not better informed about science than American adults. The combination of broad political parties organized primarily on economic issues and the general acceptance of evolution by the Catholic Church has led to broad public acceptance of evolution in most European countries. As C. P. Snow (1959) argued nearly 50 years ago, the absence of any university level study of science for non-science majors in European universities is unlikely to produce scientifically literate graduates. And these results suggest that the admittedly strong secondary school science programs in Europe are not sufficient to match the impact of general education requirement for college and university students in the United States in producing scientifically literate adults.

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The data points for Figure 1 are:

1988	9.5
1995	11.8
1999	17.2
2005	27.8

The data points for Figure 2 are:

Sweden	35.1
United States	27.8
Netherlands	23.9
Norway	22.3
Finland	22.2
Denmark	22.0
Bulgaria	19.3
Iceland	18.2
Belgium	18.1
Germany	18.0
France	17.0
Switzerland	17.0
Czech Rep.	16.8
Luxembourg	16.7
Hungary	15.3
Great Britain	14.1
E.U. 27	13.8
Estonia	12.1
Italy	11.9
Croatia	11.7
Slovakia	10.1
Austria	10.1
Ireland	9.4
Poland	9.1
Spain	8.6
Greece	6.5
Portugal	6.0
Romania	5.9
Japan	5.0
Malta	4.8
Lithuania	3.3
Cyprus	2.8
Slovenia	2.3
Latvia	2.2
Turkey	1.5