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ABSTRACT

There is growing recognition in the industrialized world that scientific literacy is an important component of long-term economic growth and of effective citizenship. Virtually every major industrialized nation has, in recent years, examined its science and mathematics education system and many have taken steps to improve the scope and quality of scientific and mathematical understanding among school graduates. Measures of scientific literacy provide a general yardstick of the proportion of adults in a society who have sufficient skills and knowledge to function effectively in citizenship and consumer roles. Previous studies have found that relatively few citizens in the United States and other industrialized nations understand basic scientific terms or can make sense of conflicting arguments from experts on issues like nuclear power. Studies of recent high school graduates in the United States do not point to significant generational improvement. This paper focuses primarily on the data from the United States and outlines some improved measures of scientific literacy with bridges to past measures. Also included is a preliminary comparison with British data. (CW)

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Scientific Literacy

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Scientific Literacy

There is growing recognition in the industrialized world that scientific literacy is an important component of long-term economic growth and of effective citizenship. Virtually every major industrialized nation has, in recent years, examined its science and mathematics education system and many have taken steps to improve the scope and quality of scientific and mathematical understanding among school graduates.

There is a strong belief that maturing economies will be increasingly dependent on information-based technologies and that new economic realities will demand an increasingly sophisticated work force. The pervasive impact of computers in financial and information processing illustrates both the speed and scope of recent changes and of even greater changes envisioned. Presently, every industrialized economy has a shortage of skilled computer-literate workers and a surplus of workers without those skills.

The growing impact of science and technology on our economies and our lives has brought an increasing number of scientific and technological issues into national political agendas. The issue of nuclear power has been a topic of continuing political dialogue in the United States and most European countries for the last two decades. The impact of acid rain and the condition of the ozone layer are increasingly subjects of both media attention and political discussion in industrialized nations throughout the world. The issue of the safety of genetically-engineered hormones in meat has triggered a trade dispute between the United States and the European Community. Unquestionably, the number and complexity of scientific and technical issues reaching the public policy agenda during the next century will increase markedly.

The proportion of citizens who have the ability to understand and follow these new scientific and technical issues is low. Previous studies have found that relatively few citizens in the United States[1] and other industrialized nations understand basic scientific terms or can make sense of conflicting arguments from experts on issues like nuclear power. Studies of recent high school graduates in the United States do not point to significant generational improvement[2].

Measures of scientific literacy provide a general yardstick (or meter stick) of the proportion of adults in a society that have sufficient skills and knowledge to function effectively in citizenship and consumer roles. I developed the first of these measures for the United States for a Daedalus article, using previously collected items from a 1979 study[3] of the public understanding of science and technology. Subsequently, I used data from a 1985 study of American adults to update the previous measure. Both of these studies found that only one in 20 American adults met a minimal definition of scientific literacy.

Having constructed those earlier measures, I am perhaps more aware than most of the need for improved measures of scientific literacy. With the support of the Science Indicators Program at the National Science Foundation, I was able to design and collect a new national survey[4] of public knowledge about science and technology in the summer of 1988. A similar study was conducted at the same time in the United Kingdom by John Durant and Geoffrey Thomas of the University of Oxford. This paper will focus primarily on the data from the United States (with which I have worked more extensively) and

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[1]See Miller, Jon D., Scientific Literacy: A Conceptual and Empirical Review, Daedalus, 112(2):29-48 (1983), and Miller, Jon D. Scientific Literacy in the United States, in Evered, David and Maeve O'Connor (Eds.), Communicating Science to the Public, (London: Wiley and Sons, 1987).

[2]National Assessment of Educational Progress. The Science Report Card (Princeton, NJ: Educational Testing Service, 1988).

[3]Miller, J. D.; K. Prewitt; and R. Pearson. The Attitudes of the U.S. Public toward Science and Technology. A final report to the National Science Foundation. (Chicago: National Opinion Research Center, 1980).

[4]The 1988 study was sponsored by the National Science Foundation (NSF grant SRS-8807409). All of the findings and conclusions reported in this paper are the responsibility of the author and do not necessarily reflect the views of the NSF or its staff.

will outline some improved measures of scientific literacy, with bridges to my past measures. I will also report a preliminary comparison with the British data.

THE CONCEPT OF LITERACY

If we are to understand the concept of scientific literacy, we must begin with a thorough understanding of the concept of "literacy" itself. We must seek to understand both the historic origins and contemporary measurements of basic literacy.

The level of skill or ability in reading and writing should be viewed as a continuum, ranging from virtually no skills to the most sophisticated of writers. For most purposes, we characterize this kind of distribution with means, medians, and standard deviations. While we sometimes report the median reading or skill level for school populations, that kind of measure is rarely used to characterize adult populations.

In contrast to a continuous distribution, literacy is a threshold measure. 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. Literacy is most often presented as a dichotomy -- literate versus illiterate -- precisely because it is a threshold measure. The focus on minimal skill levels is inherent in the concept of literacy.

Historically, an individual was thought of as literate if he or she could read and write their own name. The person who had to sign his or her name with an "X" was defined as "illiterate." I can recall reading social science textbooks as a high school student in the late 1950's that proclaimed that the United States was the first nation to achieve "universal literacy."

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. The social science and educational literature now tells us that about a quarter of Americans are not "functionally literate."

The changing definition of literacy suggests some important characteristics of the basic concept. First, the level of skills needed to be considered literate changes over time. It is inherently a relative measure -- not an absolute standard.

Second, given the diversity of social and economic systems on this planet, it is surely true that the same definition of functional literacy would not be appropriate for both advanced industrial societies and third-world agricultural societies. Any definition of literacy is inherently relative to the character of the society in which it is used.

Finally, the selection of a threshold level for the definition of literacy is not an exact science, but rather a judgment by those who understand a subject about the minimal acceptable level of knowledge or skill required to function in some set of roles in a specific society. In regard to basic literacy, for example, the literature indicates that there are several different tests or measures of functional literacy, reflecting the perceptions of each test author about the mix of skills necessary to function in society. A comparison of several of those tests, however, reveals that all are testing a common domain of skills and that there is a fair consensus on the kinds of skills and knowledge needed to be classified as functionally literate.

The problems associated with basic literacy in our society are serious and relevant to our concerns about a broader public understanding of science and technology. For those millions of Americans who are not functionally literate, the world of science is as distant as Pluto. And a very high proportion of the young people who are dropping out of our school systems will join the ranks of the functionally illiterate.

In the context of this discussion, functional scientific literacy should be viewed as the level of understanding of science and technology needed to function minimally as citizens and consumers in our society. A definition of scientific literacy does not imply an ideal or even acceptable level of understanding, but rather a minimal level. The finding that in 1985 only five per cent of American adults met a lenient definition of this minimal level should indicate the magnitude and seriousness of the problem.

A THREE-DIMENSIONAL MEASURE OF SCIENTIFIC LITERACY

In previous studies, I have suggested that scientific literacy demands (1) an understanding of the process or methods of science for testing our models of reality, (2) a basic vocabulary of scientific and technical terms and concepts, and (3) an understanding of the impact of science and technology on society. I have found this three-dimensional approach to thinking about scientific literacy to be useful and have utilized that framework with the 1988 studies. Since my revised measure involves changes in the items used to measure two of the three dimensions, it may be helpful to review briefly some of the previous measures used in regard to each dimension and to outline the 1988 changes.

Understanding the Process of Science

The systematic study of the scientific literacy of the public emerged in the 1930's as a result of Dewey's article[5] "The Supreme Intellectual Obligation," in which he declared that

> The responsibility of science cannot be fulfilled by methods that are chiefly concerned with self-perpetuation of specialized science to the neglect of influencing the much larger number to adopt into the very make-up of their minds those attitudes of open-mindedness, intellectual integrity, observation, and interest in testing their opinions, that are characteristic of the scientific attitude.

Reflecting Dewey's basic charge, I. C. Davis[6], a prominent science educator of the period, defined the scientific attitude:

> We can say that an individual who has a scientific attitude will (1) show a willingness to change his opinion on the basis of new evidence; (2) will search for the whole truth without prejudice; (3) will have a concept of cause and effect relationships; (4) will make a habit of basing judgment on fact; and (5) will have the ability to distinguish between fact and theory.

[5]Dewey, John. The Supreme Intellectual Obligation. Science Education, 18:1-4 (1934).

[6]Davis, I. C. The Measurement of Scientific Attitudes. Science Education, 19:117-122 (1935).

Hoff[7] and Noll[8] offered similar definitions and began the task of developing items for use in testing. Virtually all of the empirical work before the Second World War focused on the development of the scientific attitude, or what I have been calling an understanding of the process of science.

The effort to construct sound empirical measures of adherence to scientific thinking continued throughout the post-war years. Beginning in the mid-1960's, the National Assessment of Educational Progress (NAEP) began to collect data concerning the level of achievement in science, mathematics, and other subjects from national probability samples of precollegiate students. The NAEP studies are particularly noteworthy since they were the first national data collection program that eliminated the bias of self-selection inherent in voluntary testing programs like the Scholastic Aptitude Test (SAT). The NAEP studies were also the first attempt to collect measures of the understanding of the norms and processes of science from national samples of young people.

Schwirian[9] used factor analysis to develop a five-dimensional measure of scientific thinking. The five dimensions -- rationality, utilitarianism, universalism, individualism, and belief in progress and meliorism -- were patterned after Barber's analysis[10] of science and the social order. The Schwirian scale was originally tested on samples of undergraduates from a midwestern university and has since been used by other researchers in a number of local studies, but has yet to be used on either a national or broad population sample.

Although numerous attempts have been made over several decades to define and measure scientific thinking among school-age and young adult populations, the first national study to attempt to measure adult comprehension of the

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[7]Hoff, A. G. A Test for Scientific Attitude. School Science and Mathematics, 36:763-770 (1936).

[8]Noll, V. H. Measuring the Scientific Attitude. Journal of Abnormal and Social Psychology, 30:145-154 (1935).

[9]Schwirian, P. M. On Measuring Attitudes toward Science. Science Education, 52:172-179 (1968).

[10]Barber, B. Science and the Social Order (New York: Free Press, 1962).

scientific process was a 1957 study[11] sponsored by the National Association of Science Writers (NASW). In that study, each of the 2000 respondents were asked to define the meaning of scientific study, and the open-ended response was coded into a set of categories that reflected various levels of comprehension of the process of theory formulation and testing. Withey[12] concluded that only about 12 per cent of American adults could be said to have a reasonable understanding of the concept of scientific study.

The same open-ended question about the meaning of scientific study has been repeated in national U. S. studies in 1979, 1985, and 1988 and in a national British study in 1988. This item is the core of my measure of the public understanding of the process of science. While the coded responses have shown a generally consistent pattern over their several uses, some of the responses are sufficiently vague or marginal to make reliance on this single item undesirable. As a check against this open-ended question, all of my studies have included a set of items about astrology. One of the items asks respondents whether astrology is very scientific, moderately scientific, or not at all scientific[13] . To be classified as having a minimally acceptable level of understanding of the process of science in the 1979, 1985, and 1988 studies, a respondent had to be able to provide a satisfactory open-ended explanation of what it means to study something scientifically and to recognize astrology as not at all scientific.

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[11]The field work for this study was completed less than a month prior to the Soviet launch of Sputnik I in 1957, and thus represents the last measure of public understanding of science prior to be beginning of the Space Age. For a full description of the study and results, see Davis, R. C. The Public Impact of Science in the Mass Media (Ann Arbor, Michigan: University of Michigan Survey Research Center, Monograph No. 25, 1958).

[12]Withey, S. B. Public Opinion about Science and the Scientist. Public Opinion Quarterly, 23:382-388 (1959).

[13]In the 1988 British study, each respondent was asked to rate each of a series of items on a scale ranging from five for "very scientific" to one for "not at all scientific." Astrology was one of the items rated by all respondents. Even though the five-point British scale differs slightly from the three-point U.S. scale, respondents in both studies had one clearly labeled choice of "not at all scientific" and respondents who understood the approach and processes of science should have been able to select the correct response in either question.

Using this measure, nine per cent of American adults displayed a minimally acceptable level of understanding of the process of science in 1979[14] and 1985[15], and 12 per cent of adults qualified in 1988. Since the same items and virtually identical coding procedures were employed in the three studies, it would appear that there has been a small increase in the proportion of American adults who understand the process of science, although the absolute number is sufficiently low to discourage excessive pride in the magnitude of the increase.

Understanding Basic Scientific Terms and Concepts

The second dimension of scientific literacy is an understanding of basic scientific constructs. The argument here is simple and clear. If an individual cannot comprehend basic terms like atom, molecule, cell, gene, gravity, or radiation, then it would be nearly impossible for that person to follow much of the public discussion of scientific results or public policy issues pertaining to science and technology. In short, a minimal scientific vocabulary is necessary if one is to be scientifically literate.

As the use of standardized testing expanded during the 1950's and 1960's, a number of tests were developed to measure a student's knowledge of basic scientific constructs[16]. The majority of these tests have been used by teachers and school systems to evaluate individual students, to determine admission or placement, or for related academic counseling purposes. While some test-score summaries have been published by the Educational Testing Service (ETS) and other national testing services, these reports reflect only those students who plan to attend college or who have elected to take the test for some reason. Although very large numbers of tests are taken each

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[14]Miller, J. D. Scientific Literacy: A Conceptual and Empirical Review. Daedalus, 112(2):29-48 (1983).

[15]Miller, J. D. Scientific Literacy in the United States, in D. Evered and M. O'Connor (Eds.), Communicating Science to the Public (London: Wiley, 1987).

[16]Buros, O. K. The Sixth Mental Measurements Yearbook (Highland Park, NJ: Gryphon Press, 1965).

year, the self-selected nature of the student populations involved continues to raise substantial problems for analysis and interpretation.

The first and largest national data set to provide cognitive science knowledge scores for a broad probability sample of students in the United States was the National Assessment of Educational Progress (NAEP). For two decades, the periodic tests of the NAEP have collected measures of cognitive science knowledge from national samples of 9, 12, and 17-year-olds. On the basis of five assessments between 1969 and 1986, the National Assessment[17] found declining science achievement scores for all age groups and for almost all social and demographic groups.

In contrast to the substantial national effort to measure student knowledge of science and mathematics, there have been relatively few attempts to collect measures of scientific and technical knowledge from national samples of adults. The 1957 NASW study included a few knowledge items. In the early 1970's, the National Assessment conducted two studies of the science knowledge of young adults aged 26 to 35. The reasons for this dearth of adult knowledge measures are immediately apparent. Most adults do not like to be tested on any subject matter, and the low levels of actual knowledge about science appears to heighten adult reluctance to be tested or measured in this regard.

Beginning in 1979, a series of surveys[18] of national probability samples of adults has included a series of knowledge items. In 1979, Miller and Prewitt introduced the idea of a series of two-part knowledge items that first asked each respondent to rate their own comprehension of a term. If the respondent reported that he or she had a clear understanding or a general sense about a term, they were asked to explain what the word or phrase meant in an open-ended response. If a respondent indicated that he or she had little understanding of a word, term, or concept, they were not asked for

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[17]National Assessment of Educational Progress. <u>The Science Report Card</u> (Princeton, NJ: Educational Testing Service, 1988).

[18]The 1979, 1981, 1985, and 1988 studies were sponsored by the NSF Science Indicators Unit. The 1983 study was sponsored by the Annenberg School of Communication at the University of Pennsylvania, with funding from the NSF Public Understanding of Science Program.

further explanation. This approach makes the collection of knowledge data from adult populations more acceptable to respondents, reduces unproductive time in the interview, and reduces the coding burden from open-ended answers.

In all of these surveys, the open-ended question about the meaning of scientific study has initiated the series. It is a difficult question for many respondents. Initially, there is a tendency for respondents to over-estimate their level of knowledge about an item, but the effect of the first probe on the meaning of scientific study appears to have the effect of reducing the tendency to over-estimate one's level of information. Using this observation, the scientific knowledge measure used in the 1979 and 1985 studies was based on the self-reported knowledge items for radiation, DNA, and GNP. These same items were repeated in the 1988 U.S. study, allowing a time series comparison. In both 1988 and 1985, 34 per cent of American adults reported at least one clear understanding and one general sense on these three items, thus meeting a minimal criterion for scientific vocabulary.

From the outset, I have recognized the inadequacy of this estimate of the understanding of scientific terms and concepts. The original 1979 scientific literacy estimate was made three years after the 1979 data collection, thus eliminating the possibility of designing items for this purpose. The 1985 study allowed a replication of the 1979 measures, but time and space constraints prohibited a more extensive exploration of the knowledge dimension. Fortunately, one of the primary purposes of the 1988 study was the development and improvement of the scientific literacy measures and it has been possible to make substantial progress in this area.

In the 1988 studies in the U.S. and the U.K., an expanded number of scientific and technical knowledge items were included. Some of these items were included in a true-false quiz format while others were posed as free standing questions. While each study included 15 to 20 scientific and technical knowledge items, ten of the items were identical in the two studies and displayed sufficient variance to be useful in index construction. Respondents received one point each for a "true" response to the following items:

The oxygen we breathe comes from plants. Is that true or false?

Electrons are smaller than atoms. Is that true or false?

The universe began with a huge explosion. Is that true or false?

The continents on which we live have been moving their location for millions of years and will continue to move in the future. Is that true or false?

Human beings, as we know them today, developed from earlier species of animals. Is that true or false?

Respondents received one point for each "false" response to the following items:

Lasers work by focusing sound waves. Is that true or false?

The earliest human beings lived at the same time as the dinosaurs. Is that true or false?

In addition, respondents received one point for providing a correct open-ended explanation of DNA, one point for indicating that light travels faster than sound, and one point for a pair of answers indicating that the Earth goes around the Sun once a year.

Each respondent could score from zero to ten on the scale and the distribution of scores indicates a normal distribution (see Figure 1). As the data demonstrate, the level of understanding of scientific terms and concepts is a continuous distribution. If we could persuade samples of adults to take longer knowledge tests similar to those administered to student populations, we would undoubtedly find similar normal distributions. For the purpose of constructing an index of scientific literacy, those respondents with a score of seven or more on this measure were classified as having an adequate level of understanding of scientific terms and concepts. About 28 per cent of American adults met this criterion in the 1988 study.

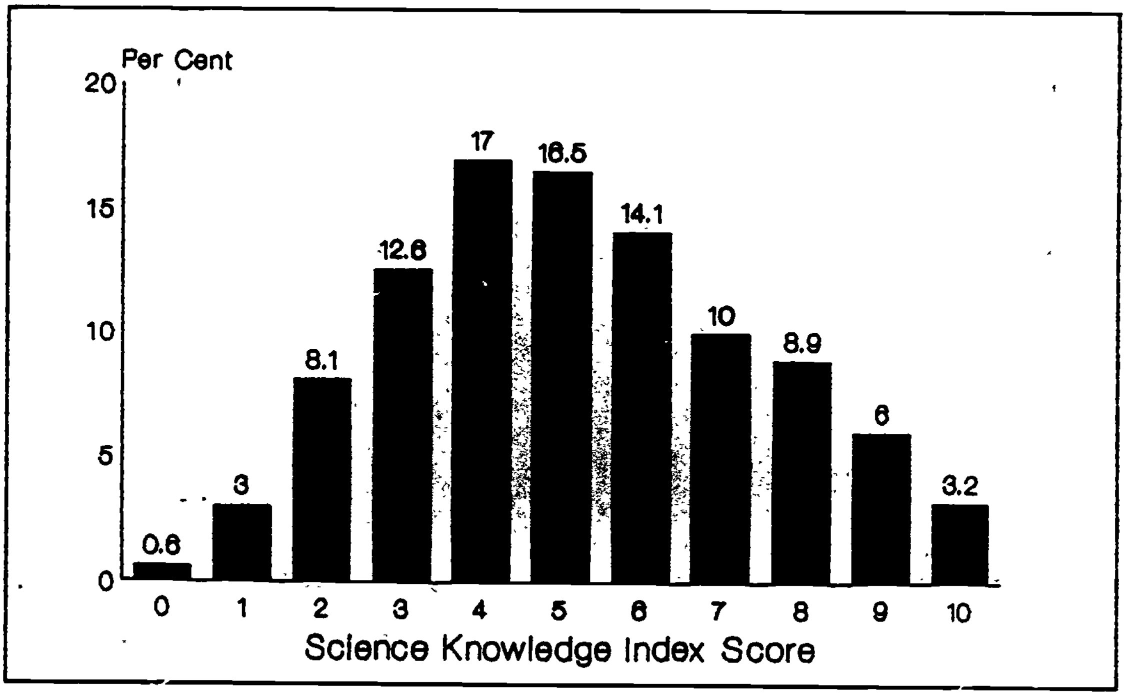

Figure 1: Distribution of Scores on the Index of Scientific Knowledge.

Understanding the Impact of Science on Society

The third dimension of scientific literacy concerns an understanding of the impact of science and technology on society broadly and on the daily life of individuals as consumers, parents, and citizens. As implemented in the 1979, 1985, and 1988 studies, this dimension has been measured with a series of items and might be thought of as "technological literacy" in a broader sense. The items in the preceding measure of scientific knowledge are important in understanding a wide range of scientific and technical material, but an understanding of the size of an electron or the time location of humans and dinosaurs would have little impact on the daily lives of most people. In contrast, some knowledge about computers or antibiotics or radioactivity might assist an individual in coping with some of the technologies and public policy issues that he or she may confront currently.

For the 1988 study, a six-item index was constructed to measure this social impact of technological literacy dimension. Respondents received one point for providing a "false" response to the following items:

Radioactive milk can be made safe by boiling it. Is that true or false?

Antibiotics kill viruses as well as bacteria. Is that true or false?

In addition, respondents received one point each for indicating that not all radioactivity is man-made, that eating animal fat is the leading cause of heart disease, and that all of the children of a couple with a one-in-four chance of transmitting a genetic condition would have the same probability of having that condition.

Each respondent could have a score from zero to six and the distribution of scores on this measure was normal (see Figure 2). For the purpose of constructing an index of scientific literacy, respondents with a score of three or more were classified as having an adequate understanding of the impact of science, or an adequate level of technological literacy. I am not satisfied with the measurement of this dimension, but given the items that have been collected in previous studies and that were collected in 1988, it is the best estimate available. The 1988 measure is an improvement over the previous measures. I hope that increased attention can be focused on these measures in the next cycle of scientific literacy studies and that we can develop improved measures of this important dimension of scientific literacy.

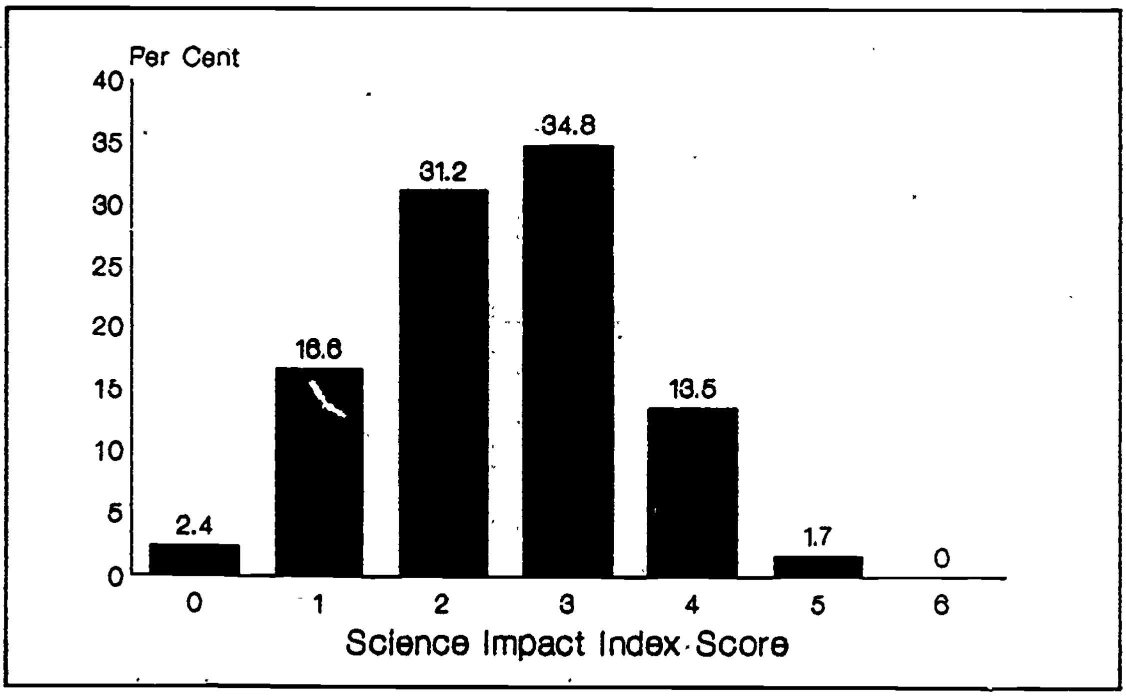

Figure 2: Distribution of Scores on the Understanding of the Impact of Science and Technology.

An Index of Scientific Literacy

To be scientifically literate, it is necessary to have a minimal understanding of the processes of science, a minimal understanding of scientific terms and concepts, and a minimal understanding of the impact of science on society. Combining the three separate indices described above, approximately six per cent of American adults can be classified as scientifically literate in 1988. Compared to seven per cent in 1979 and five per cent in 1985, this result suggests that there has been no significant change in the level of scientific literacy among American adults in the 1980's.

As a check on the changes described in preceding sections, the 1988 estimate of scientific literacy was calculated twice. One calculation used the same variables employed in 1979 and 1985, but using 1988 data. The other calculation used the new variables and the 1988 data. The overall scientific literacy estimate was 5.6 per cent in both calculations, indicating that the new measures are an appropriate bridge to previous measures. A comparison of the results on each of the three dimensions indicates the new measures produced slightly lower estimates in regard to scientific knowledge and understanding of social impact (see Table 1). The same measure of understanding of scientific process was employed in 1979, 1985, and 1988.

Table 1: A Comparison of Two Estimates of Scientific Literacy in 1988.

	Trend Measure with 1979 & 1985 Variables	New Measure with 1988 Variables
Estimate of scientific literacy	5.6%	5.6%
Understanding of scientific processes or thinking	12.1	12.1
Understanding of scientific terms and concepts	34.0	28.1
Understanding of the impact of science and technology	53.0	49.9

N = 2041

On first examination, it may appear implausible that the new measure could provide lower estimates of two of the dimensions and still produce the same overall estimate. This occurs because the new estimates have a higher correlation with each other, indicating that they are doing a better job of estimating the central concept. In practical terms, the old measures appear to have identified some individuals as having an adequate understanding of scientific terms and concepts, for example, but who did not have comparably high scores on the other dimensions. In general, these results suggest that the new indices are better measures than the older measures and that the new estimates, if used in future years, will not disrupt the time series from 1979 and 1985.

WHO IS SCIENTIFICALLY LITERATE?

Having estimated that only six per cent of American adults are scientifically literate, it is reasonable to examine the distribution of scientific literacy in American society. Previous studies have found that scientific literacy is strongly associated with college education and that men are more likely to be scientifically literate than women. The 1988 data provide an opportunity to examine these previous findings and explore some new explanations of the distribution of scientific literacy.

Age, gender, and education are standard demographic measures. For this analysis, age was trichotomized into 18-29, 30-50, and 51 and over. Education was trichotomized into less than high school graduation, high school graduates, and baccalaureates. Gender was dichotomized in the traditional manner.

In addition to the level of formal education, previous studies[19] have found that exposure to a college-level science course is also important. In the 1988 study, each respondent was asked if he or she had completed any college-level courses in biology, chemistry, or physics. Approximately 40 per cent of the respondents reported having had one or more college-level science courses (which could have included community college courses) and this

[19] Miller, Daedalus; Miller, Communicating.

variable was dichotomized into no courses versus some courses for this analysis.

Finally, this analysis includes a measure that reflects whether the respondent's employer is engaged in scientific or engineering work. In subsequent analyses, the impact of a number of work related factors (use of computers, years of professional preparation) will be explored, but for this analysis, the single measure concerning the conduct or sponsorship of science will be employed. The advantage of this variable is that it includes all employees, so that both a secretary and a scientist in a scientific laboratory would be included. For the minimal levels of knowledge tested in this measure of scientific literacy, it is possible that numerous individuals who are not formally trained in science or engineering but who are routinely exposed to scientific information may acquire both an interest in and some level of literacy concerning it.

To assess the relative influence of each of these five variables on scientific literacy, a stepwise logit model will be employed, following the procedures described by Goodman[20] and Fienberg[21]. For readers not familiar with this terminology, a logit model is analogous to a regression model, but it uses categories rather than interval measures and it seeks to predict cell populations rather than points or surfaces in space. A stepwise model means that the variables are entered into the model one at a time, allowing the first variable entered to account for the maximum amount of variation possible. The second variable entered into the model then accounts for the maximum amount of the remaining variation, and this process continues until all of the variables have been entered into the model. It is analogous to stepwise regression models.

Applying this technique to the 1988 scientific literacy data, the effect of working for an employer who engages in scientific work was entered into the model first (since it is the most current or proximate variable) and it

[20]Goodman, L. A. Analyzing Qualitative/Categorical Data: Log-linear Models Latent Structure Analysis (Cambridge, MA: Abt Books).

[21]Fienberg, S. E. The Analysis of Cross-classified Categorical Data (Cambridge, MA: Massachusetts Institute of Technology Press, 1978).

accounted for 10 per cent of the total mutual dependence[22] in the model (see Table 2). The effect of a college-level science course was entered second and it accounted for 39 per cent of the mutual dependence. The level of formal education completed explained an additional 10 per cent of the mutual dependence. With employment, science courses, and formal education already in the model, the results indicated that an individual's age had no additional predictive power. Finally, holding constant the variables already entered into the model, the respondent's gender accounted for about 10 per cent of the mutual dependence. The combination of all five of these direct effects accounted for 72 per cent of the total mutual dependence in the model, which is analogous to a Multiple R^2 in regression. This is a good fitting model.

Table 2: A Stepwise Logit Model to Predict Scientific Literacy.

	d.f.	LRX^2	CMPD
Independence model	71	187.4	--
Effect of employment in scientific firm	1	19.1	.102*
Marginal effect of college science courses	1	73.2	.391*
Marginal effect of the level of education	2	19.3	.103*
Marginal effect of respondent age	2	4.7	.025
Marginal effect of respondent gender	1	18.4	.098*
Total of all direct effects	7	134.7	.719*

Legend:
- * Significant at the .01 level.
- d.f. Degrees of freedom.
- LRX^2 Likelihood-Ratio Chi-square.
- CMPD Coefficient of Multiple-Partial Determination.

[22]Goodman suggests that mutual dependence be used rather than variance or variation to denote the difference between the predicted values from the independence model and the observed values.

These results are similar to those found in 1979 and 1985. Exposure to a college-level science course remains a major source of adult scientific literacy. While obtaining a baccalaureate added marginally to the likelihood of being scientifically literate, it is clear that it is the science course experience rather than the general degree experience that makes a difference. By inference, this result suggests that the high school science experience has little impact on subsequent adult scientific literacy.

The persistent and continuing finding of a significant gender difference points to a gender role differentiation in American society concerning science. It is important to understand that in the model reported above, the gender difference is a residual effect, with employment, education, and exposure to college-level science courses held constant. The explanation of this difference must be found elsewhere. Most likely, we are observing the results of the stereotyping of science as a male realm.

A PRELIMINARY COMPARISON WITH THE UNITED KINGDOM

All of the measures used to construct the estimate of scientific literacy for the United States were also collected in the United Kingdom at approximately the same time[23]. The interview contents were coordinated to assure the maximum amount of commonality between the two studies, recognizing that each study also served somewhat different internal purposes and that some of the contexts were different. Nevertheless, a substantial number of items were asked in identical or comparable forms, allowing some preliminary discussion of the results.

It is important to understand the continuing nature of this work. From the earliest stages of planning, we have all been aware that our measures of scientific literacy are evolving and that we must seek to develop better questions and indices. As noted above, I think that the new scales that I have developed on the U.S. data are a step forward and that they bridge

[23]The British study was directed by John Durant and Geoffrey Thomas from the University of Oxford, with funding from the Economic and Social Research Council (ESRC). The 2009 personal interviews were conducted in the respondent's home by the Social and Community Planning Research (SCPR) unit in London.

nicely to my previous measures. My British colleagues have included a wider range of measures, especially concerning the understanding of the processes of science, and they are currently continuing their analysis of those additional items. Hopefully, they will construct yet better measures and we can replicate those measures in future studies in the U.S. and other countries. This comparison, however, is based on only the duplicate questions included in the two studies.

When the measures described in the preceding sections of this paper are applied to the British data, approximately seven per cent of British adults qualify as scientifically literate (see Table 3). There is a remarkable degree of similarity in the response patterns of the American and British respondents. The only significant difference between the two populations was the slightly higher proportion of British respondents who understood the impact of science on society. The scores on the level of understanding of scientific terms and concepts was virtually identical.

Table 3: Scientific Literacy in the United States and the United Kingdom.

	United States	United Kingdom
Estimate of scientific literacy	5.6%	7.1%
Understanding of scientific process	12.1	10.4
Understanding of scientific terms and concepts	28.1	28.5
Understanding of the impact of science and technology	49.9	57.6
N =	2041	2009

A great deal of work remains to be done to fully understand the components used in this comparison. We have tried to match our coding of open-ended answers as closely as possible. Despite the general belief that the same language is spoken in both the U.S. and the U.K., we find some interesting differences in the open-ended responses. We are continuing our examination of these coding protocols and there may be some minor adjustments in the months ahead.

In regard to the understanding of the impact of science, in which the British respondents scored higher than their American counterparts, an examination of some of the items is interesting. On the open-ended item asking what is computer software, 49 per cent of U.S. respondents were able to provide a correct response in contrast to 26 per cent of British respondents. This difference may reflect the wider use of computers in work and home in the U.S. Conversely, 75 per cent of British respondents knew that some radiation occurs naturally (in contrast to 65 per of Americans) and 66 per cent of U.K. respondents were able to interpret the meaning of the one-in-four probability of having an inherited disease (in contrast to 57 per cent of Americans). Americans were slightly more likely to know that eating animal fat is the major cause of heart disease.. While it is hazardous to make broad conclusions from these limited data, it would appear that U.S. respondents did better on items like computing (to which they have more exposure) and heart disease (which has been the subject of extensive public information campaigns in recent years) and less well on probability and radiation, which may be more likely learned in school settings.

SOME CONCLUSIONS

The central point about both the U.S. and the U.K. results is that only about one in 20 adults in either society qualified as scientifically literate, using an improved -- but still minimal -- set of criteria. The decade (1979-1988) covered by these estimates has witnessed the continued growth of scientific achievement and the expanded impact of science and technology on our lives, our jobs, and our culture. In all industrialized societies, the number of public policy issues requiring some minimal knowledge of science or mathematics has been increasing and will undoubtedly continue to grow in the decades ahead.

In previous presentations, I have argued that the health of our democratic system is in danger when there are important public policy issues that are incomprehensible to 90 per cent of our citizenry. The minor variations in the level of scientific literacy in 1979, 1985, and 1988 are inconsequential and may be accounted for by measurement error or other noise in the system. It would be a mistake to focus on these minor deviations, or the differences between the U.S. and the U.K. The important point is that in two of the world's oldest and most prominent democracies, at least nine out of ten citizens lack the scientific literacy to understand and participate in the formulation of public policy on a very important segment of their national political agendas. The trend data from the U.S. indicates that there has been no improvement during the last decade.

The problem is clear and I think that there is broad agreement that it is real. There is also reasonably broad agreement that a central part of the solution must be found in the common school programs that most young people experience for 10 to 12 years of their lives. In the U.S. data, it is clear that it is the college science experience that makes a difference, not the pre-collegiate experience. I take that as a descriptive result, not a prescriptive conclusion. It is clear that the scope and quality of the pre-collegiate science experience must be improved substantially if the proportion of Americans who are scientifically literate is to increase. I suspect that the same is true in Britain, but I do not know enough about the scope and quality of science instruction in British schools to offer more than a speculation in that regard.

In summary, the results of my 1988 study indicates that only six per cent of American adults are scientifically literate, that we have made no progress in this regard over the last decade, and that a meaningful solution involves longer-term changes in our educational system. The British results suggest that we are not alone in our problems and I think that it is most likely a problem faced by virtually all industrialized nations. We must continue to monitor the level of scientific literacy in the United States and in other developed countries, but most importantly, we must begin to think about the programs and interventions needed to change these patterns of broad scientific illiteracy.