Biological Literacy in the 21st Century:
The key to the public understanding of medicine

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
jdmiller@msu.edu

In broad terms, the 20th century may be thought of as the century of physics. Physical scientists and engineers produced:

- **automobiles**
- **radios**
- **airplanes**
- **telephones**
- **television**
- **transistors**
- **computers**
- **satellites**
- **the Internet**
- **nuclear weapons**

In equally broad terms, the 21st century will be the century of biology. Biologists, biomedical scientists, and biotechnologists:

- **have already mapped more than 100 genomes, including the human genome.**
- **have developed computer-based technologies to speed the processing and identification of genetic material.**
- **will complete a map of all human proteins in less than a decade.**
- **will complete a genetic model of disease in another decade which will re-define health, disease, and medicine.**
- **will continue to learn about the nature of life and accrue the ability to intervene in health and disease in ways that none of us can imagine.**

In the 21st century, all citizens will need to be biologically literate in order to:

- **understand a wide range of important public policy issues such as stem cell research, genetic diseases, genetically-based medicines and therapies, genetically modified foods and products, and infectious diseases.**
- **make decisions about personal and family health matters ranging from diagnoses to inoculations to therapies to reproductive choices.**

Today and throughout the 21st century, biomedical communication will depend on having a substantial proportion of adults who can understand:

- **the role of DNA in life, heredity, disease, and health.**
- **the origins of life and the genetic linkages between humans, animals, and plants and the role of natural selection in the evolution of life.**
- **the probabilistic nature of the interaction between genetic factors and environmental factors in disease and therapy.**
- **the nature of ecosystems and the importance of biodiversity**
- **the linkage between climate, ecology, health, and survival.**

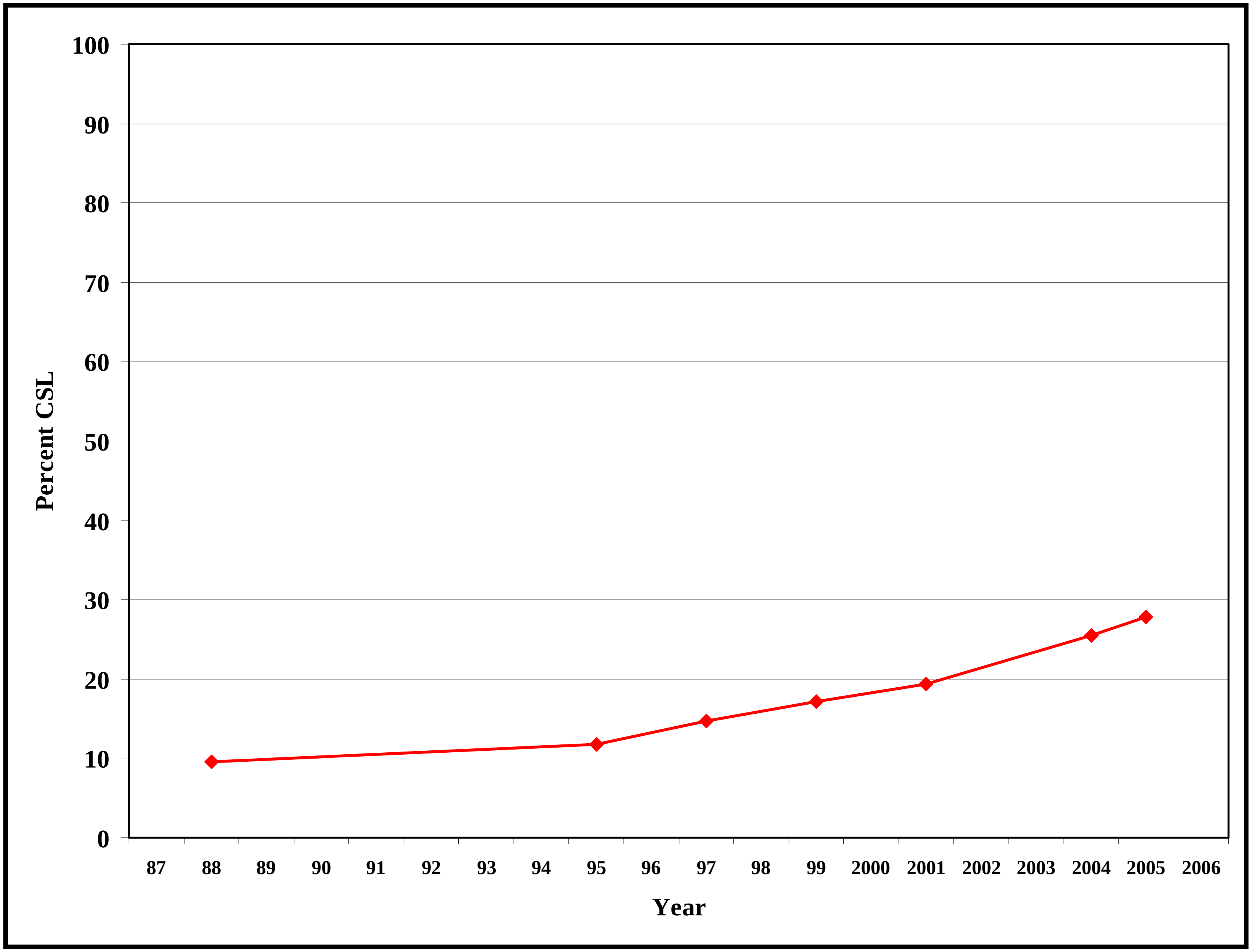
It is important to have a good measure of Biological Literacy in order to:

- understand the distribution of the ability to comprehend messages about genetic medicine for public policy and personal health reasons.
- think about the changes that need to be made in pre-collegiate and college education to prepare citizens to understand and make sense of the ongoing expansion of biological knowledge.
- measure our success or failure in expanding the number of students, young adults, and adults who are able to read, understand, and make sense of new information about current biology, medicine, agriculture, and ecology.

In recent decades, a number of national surveys of public understanding of science and technology have been conducted in the United States and other major industrial nations.

- **The National Science Board's *Science and Engineering Indicators* is perhaps the best known and most widely used of these data resources.**
- **These data have been used to construct measures of scientific literacy and have been used in more than 40 countries.**

Percent of American Adults Scientifically Literate, 1988-2005



This measure of civic scientific literacy (CSL) is a useful summary measure for many purposes, but it may overstate the level of public understanding of biological and biomedical constructs.

- **It includes a full array of scientific constructs, including a number of physical science constructs that are not relevant to biomedical issues.**
- **It includes some items about genetic and biological science but the number of biological science items is inherently limited to fit into a manageable scale.**
- **It is a good general indicator of the ability to read the Tuesday *New York Times*.**

What is needed is a good summary measure of biological literacy that includes:

- **Basic constructs about science, including some understanding of the nature of theory and experimentation.**
- **The core concepts concerning the evolution of life and the role of DNA in transmitting characteristics, propensities, and genetic errors.**
- **Items concerning the commonalities of life that span across plants, animals, and humans.**
- **Items that reflect some understanding of natural and human-directed genetic modification, including applications to medicine, food, materials, and fuels.**

Two national surveys conducted in 2003 and 2005 included a sufficiently broad set of items to allow the construction of an Index of Biological Literacy.

- **The 2003 survey included approximately 2,000 adults from the Knowledge Networks national probability panel and was the U.S. portion of a 10-country biotechnology study sponsored by the Foundation BBVA (Madrid, Spain).**
- **The 2005 survey included approximately 2,000 about from the Knowledge Networks national probability sample and was part of an evaluation of the impact of the inclusion of science information in local television newscasts. The program and the evaluation were sponsored by a grant from the NSF.**

A set of approximately 20 items were included in each survey that concerned biological science or biotechnology.

- **Confirmatory factor analyses (using LISREL) were conducted on each data set to determine that the items reflected a single dimension and that the loadings were sufficiently high to justify the inclusion of each item in the scale.**
- **The results demonstrate that all of the items load on a single common factor. These items are clearly measuring the same dimension and we will call that dimension Biological Literacy.**

Confirmatory Factor Analysis Loadings

	2003	2005
Provide a correct open-ended definition of a “stem cell.”	.75	.84
Provide a correct open-ended definition of a “molecule.”	.69	.81
Provide a correct open-ended definition of “DNA.”	.63	.76
Provide a correct open-ended definition of a “neuron.”	--	.76
Disagree: “Stem cells occur only in plants.”	--	.74
Disagree: “Ordinary tomatoes … do not have genes but genetically modified tomatoes do.”	.82	.73
Disagree: “Antibiotics kills viruses as well as bacteria.”	.68	.71
Provide a correct open-ended definition of “what it means to study something scientifically.”	.67	.71
Disagree: “Genetically modified animals are always much larger than ordinary animals.”	.70	--
Provide a correct open-ended definition of an “experiment.”	.62	.65
Disagree: “For the first time in recorded history, some species of plants and animals are dying out and becoming extinct.”	--	.62
Disagree: “Today it is not possible to transfer DNA from humans to animals.”	.65	--
Disagree: “If someone eats a genetically modified fruit, there is a risk that the person’s genes might be modified too.”	.65	.57
Agree: “During the first months of pregnancy, it is possible to apply a genetic test to determine whether the baby will have Down’s syndrome.”	.60	--

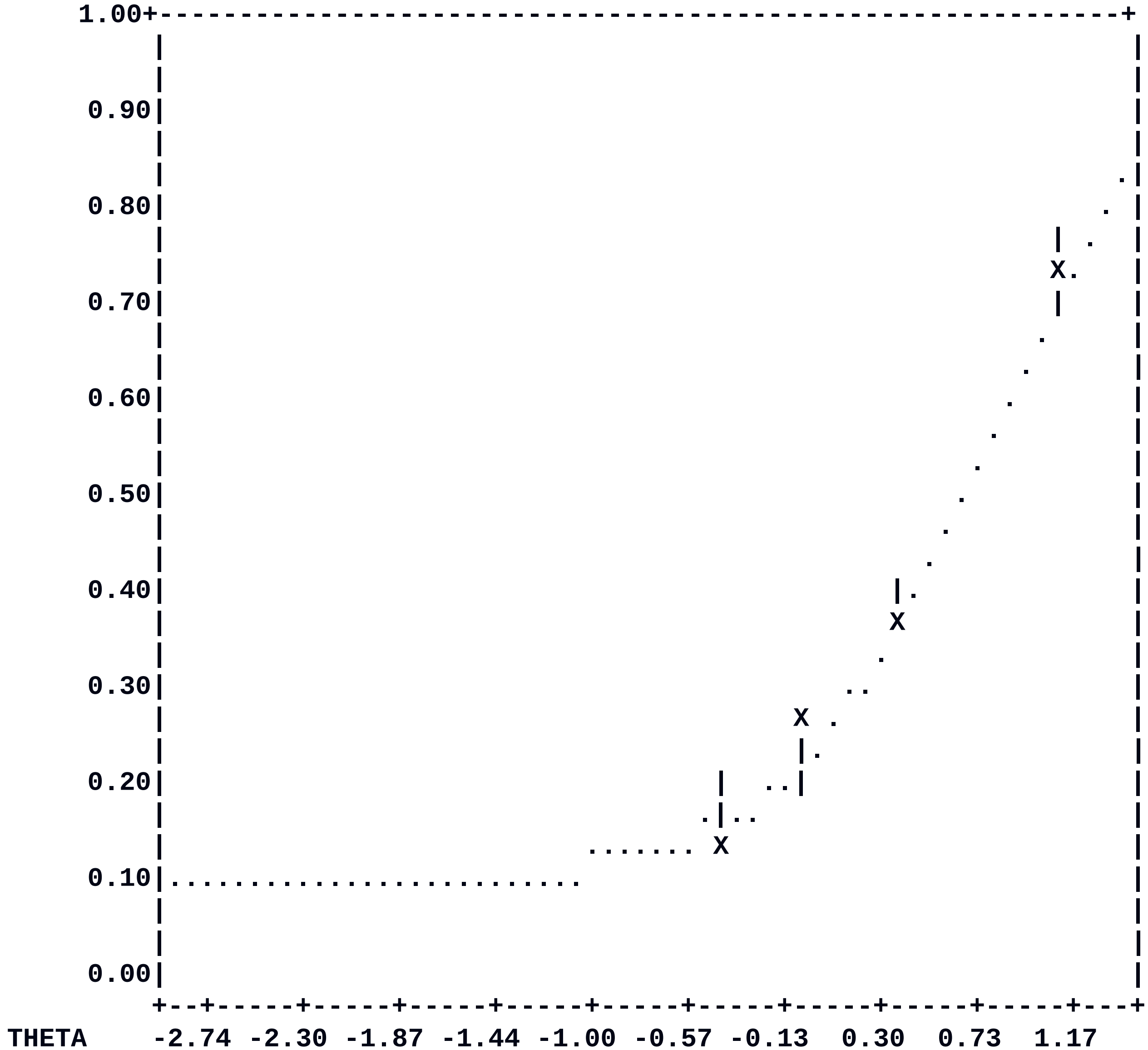
Confirmatory Factor Analysis Loadings

	2003	2005
Agree: “More than half of human genes are identical to those of mice.”	--	.57
Disagree: "The earliest humans lived at the same time as the dinosaurs."	.54	.55
Agree: “All plants and animals have DNA.”	.67	.54
Agree: “Over periods of millions of years, some species of plants and animals adjust and survive while other species die and become extinct.”	--	.54
Disagree: “Today it is not possible to transfer genes from animals to plants.”	.59	--
Disagree: “All humans share exactly the same DNA.”	.56	--
Disagree: “Humans have somewhat less than half of their DNA in common with chimpanzees.”	.53	.50
Agree: “The greenhouse effect causes the Earth's temperature to rise.”	.54	.45
Indicate a correct understanding of the meaning of the probability of one in four.	.45	.45
Disagree: “Biomedical scientists are now able to create new genes that have never existed in nature before.”	--	.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.”	--	.38
Agree: “Human beings, as we know them today, developed from earlier species of animals.”	.44	.33

It is also important to examine the response characteristics of each of the items to be included in the Index of Biological Literacy.

- **For this purpose, an Item-Response-Theory (IRT) analysis of the combined set of items (both years) was conducted, using BILOG-MG.**
- **An item response curve shows the proportion of respondents who are able to provide a correct answer for each item at each point on a tentative scale of biological literacy.**
- **A good item will have a strong slope and the set of items will vary in the level of difficulty.**

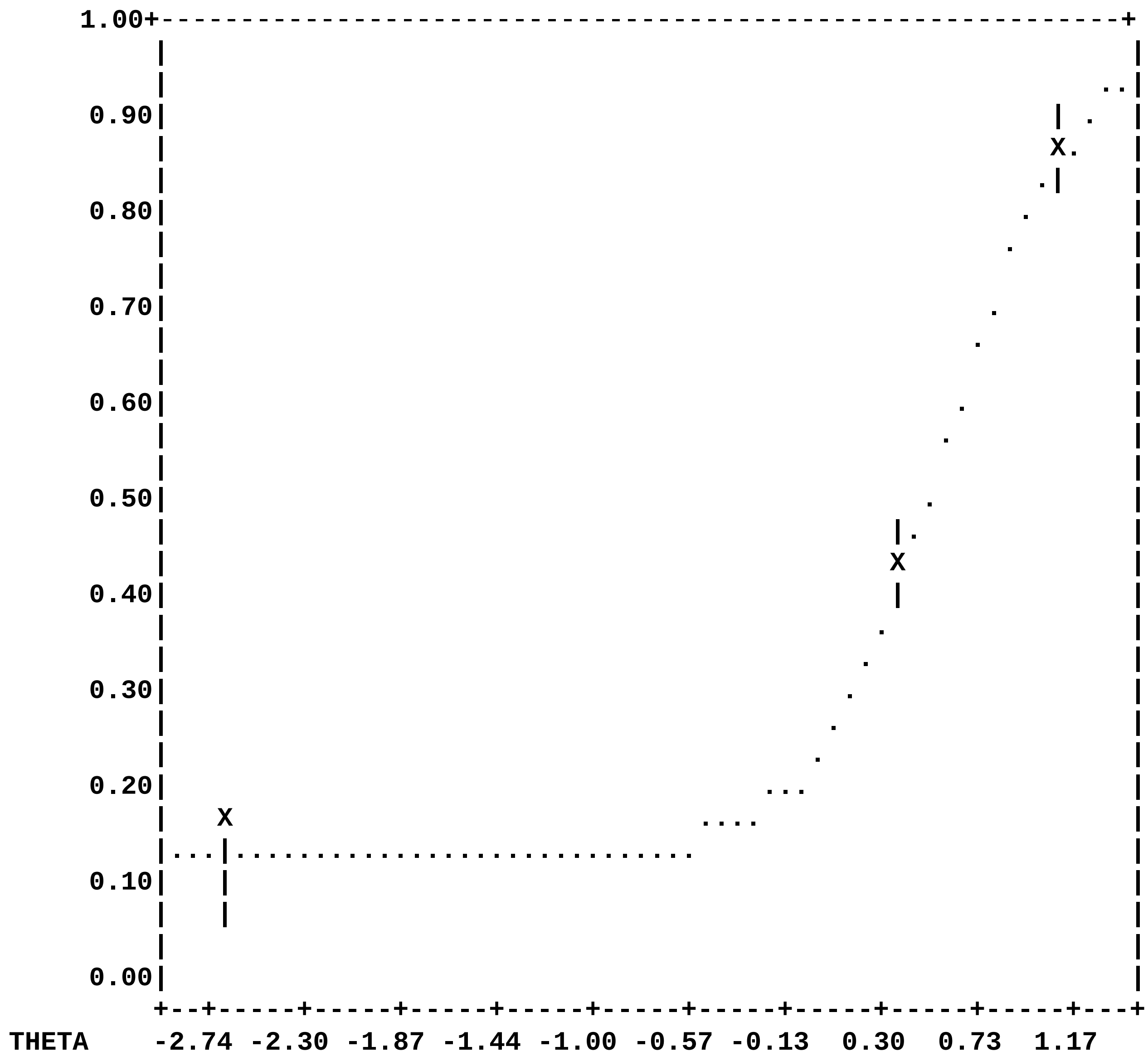
Item Response Curve for the understanding of an experiment



Item Response Curve for understanding an antibiotic

```
      1.00+------------------------------------------------------------+
          |                                                            |
          |                                                          ..|
      0.90|                                                       ...  |
          |                                                     ..     |
          |                                                   ..       |
      0.80|                                                  .         |
          |                                                 .          |
          |                                               ..           |
      0.70|                                             |.             |
          |                                             |              |
          |                                            .|              |
      0.60|                                           .                |
          |                                          .  X              |
          |                                         .                  |
      0.50|                                                            |
          |                                        .                   |
          |                                       .                    |
      0.40|                                      .                     |
          |                                    ..                      |
          |                                  X.                        |
      0.30|                                  |                         |
          |                                ..|                         |
          |                              ..                            |
      0.20|                            ..                              |
          |        |     |         ....                                |
          |        |     X ........                                    |
      0.10|........|.....|.                                            |
          |        X     |                                             |
          |                                                            |
      0.00|                                                            |
          +--+-----+-----+-----+-----+-----+-----+-----+-----+-----+---+
 THETA    -2.74 -2.30 -1.87 -1.44 -1.00 -0.57 -0.13  0.30  0.73  1.17
```

Item Response Curve for understanding a stem cell



To obtain individual scores, each item is calibrated on three dimensions:

- **The THRESHOLD is the point at which half of a given ability group (segments of the ability estimate) provide a correct answer to the item. This is sometimes referred to as the difficulty parameter.**
- **The SLOPE is the beta coefficient of the slope of the item curve shown in the previous item response curves.**
- **The GUESSING PARAMETER is a correction factor that takes into account the guessing probability on closed-ended items.**

On the basis of these three parameters and whether or not a respondent was able to answer each item correctly, an individual score is obtained.

- **The individual score is a standardized score with a mean of zero and a standard deviation of 1.0.**
- **For the purpose of reporting scores on the Index of Biological Literacy, the mean is set to 50 and the standard deviation is set to 20. This conversion produces a distribution of scores from approximately zero to 100.**
- **Individuals with a score of 70 or higher are considered to be biologically literate.**

Using the results of the IRT model and the scoring procedure just described:

- **9% of American adults were biologically literate in 2003.**
- **16% of American adults were biologically literate in 2005.**
- **Comparatively, 28% of American adults qualified as scientifically literate in 2005.**

Why are fewer American biologically literate than scientifically literate?

- These results indicate that more Americans are knowledgeable about physical science constructs – the structure of matter, the structure of the solar system, and the geology of the Earth -- than biological constructs, especially genetics, evolution, and heredity.
- The Index of Biological Literacy included a higher proportion of genetic and heredity items than the Index of Civic Scientific Literacy.
- This is a reasonable and fair result because it will be necessary for adults to understand core genetic constructs to understand the advances of modern biology in medicine, agriculture, and ecology.

Which Americans are biologically literate?

Men were slightly more likely to be biologically literate. Gamma = -.22 in 2005. Gamma not significant in 2003.

	2003	2005
All Adults	9%	16%
Gender		
Male	11	19
Female	8	13
Number of Cases	1,600	1,484

Education is strongly correlated with biological literacy. Gamma = .70 in 2003 and .69 in 2005.

	2003	2005
All Adults	9%	16%
Education		
Less than high school completion	1	1
High school diploma or GED	1	7
Some post-secondary	7	20
Baccalaureate	18	31
Graduate or professional degree	31	46
Number of Cases	1,600	1,484

Younger adults were slightly more likely to be BL. Gamma = -.16 in 2003 and -.22 in 2005.

	2003	2005
All Adults	9%	16%
Age		
18 to 29 years	9	17
30 to 39 years	15	18
40 to 49 years	7	17
50 to 59 years	14	17
60 to 69 years	5	19
70 or more years	5	6
Number of Cases	1,600	1,484

Scientifically literate adults were more likely to be BL.

	2003	2005
All Adults	**9%**	**16%**
Civic Scientific Literacy		
Scientifically Literate	**41**	**53**
Not Scientifically Literate	**0**	**0**
Number of Cases	**1,600**	**1,484**

We are still in the early stages of exploring the implications of this new measure of biological literacy, but several points merit discussion.

- **There can be little doubt that efforts to communicate about biomedical science will benefit from a larger proportion of adults who are biologically literate.**
- **Reliance on patient trust in physician judgment is not a reasonable long-term solution.**
- **As we see in the current stem cell debate in this country, an absence of understanding does not default to trust in the science and medicine. We cannot allow the future of biomedical policy to rest primarily on the politics of religion.**