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'Scientific Literacy: The Missing Link'

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The earth revolves with me, yet makes no motion,
The stars pale silently in a coral sky.
In a whistling void I stand before my mirror,
Unconcerned, and tie my tie.

(Aiken, 1953)

Why Scientific Literacy?

A senior student, preparing to teach science, recently responded to a question on the nature and evolution of science in the following way. "The nature of science involves categorizing and labeling." Another responded, "The nature of science is explanation. [Science] grows as men [sic] pour money into its development because they see an opportunity to control other men [sic]." The answers of these would-be teachers show little understanding of science—as an intellectual endeavor or as a process. Instead they reveal a basic lack of scientific literacy. Yet, these students are science majors; I shudder to ponder the responses of humanities, education, agriculture, or—even—engineering students.

While you and I can appreciate the beauty of an elegant experiment, can ponder the interrelationship of science and technology, can argue the merits or virtues of applied versus pure science, even we may have difficulty articulating a concise definition of scientific literacy. And without a precise conceptualization, we may question its importance. Yet, as we move toward a "technocracy" in which the opportunity—indeed the privilege—of employment as well as the quality of life is increasingly based on literacy in the sciences, its importance grows.

Twenty-five years ago, C.P. Snow's small volume, *The Two Cultures*, alerted scientists and humanists alike to the existence of two cultures and to the schism between them. He wrote:

> At one pole, the scientific culture really is a culture, not only in an intellectual but also in an anthropological sense. That is, its members need not, and of course often do not, always completely understand each other; biologists more often than not will have a pretty hazy idea of contemporary physics; but there are common attitudes, common standards and patterns of behaviour, common approaches and assumptions.
>
> At the other pole, the spread of attitudes is wider. . . . But I believe the pole of total incomprehension of science radiates its influence on all the rest. That total incomprehension gives, much more pervasively than we realise, living in it, an unscientific flavour to the whole 'traditional' culture, and that unscientific flavour is often, much more than we admit, on the point of turning anti-scientific.
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> (Snow, 1961, p. 10-11.)

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Recently, the schism between the scientific and traditional cultures has widened to a chasm, and scientific literacy may be the only way to bridge the gulf. I maintain that scientific literacy can provide the "missing link" between the two cultures, enabling the scientists and non-scientists to communicate intelligently and to act with wisdom. It also can provide the cognizance so that we no longer stand before mirrors and unconcerned, tie our ties.

What is Scientific Literacy?

To be literate is to be able to read and write, yet 12% of our population cannot do so. To be functionally literate is to be able to respond correctly to simple written questions about everyday modern life, yet 20% of American 17-year-olds fail such a task. To be scientifically literate is to be able to read about, comprehend, and express an opinion on scientific matters, yet 70% of the public cannot do so. (Figure 1)

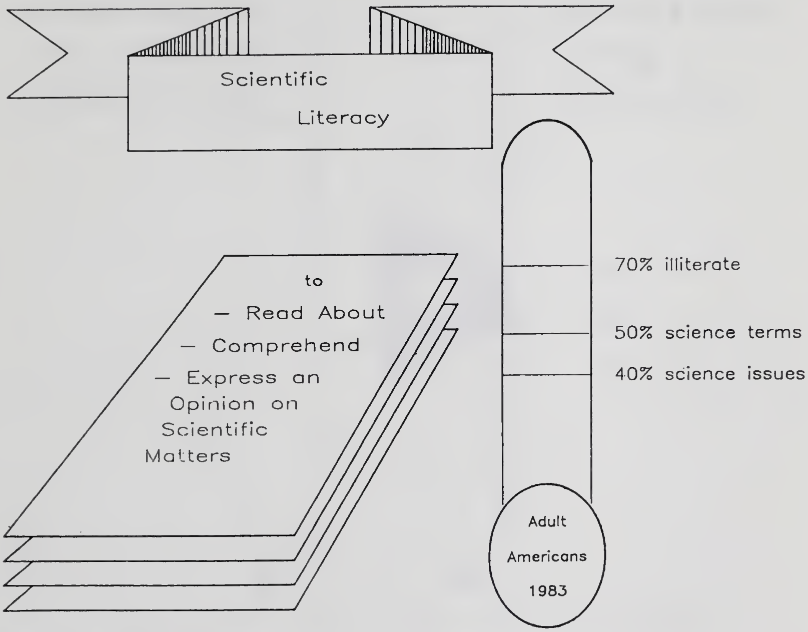

Figure 1. Science Literacy.

Scientific literacy is composed of three dimensions:

* An understanding of the norms of science,
* A knowledge of the major scientific constructs, and
* An awareness of the impact of science and technology on society and the policy choices that must inevitably emerge.

(Miller, 1983, p. 31.)

How well does John or Jane Q. Public understand each of these three dimensions? A detailed National Science Foundation survey of adult attitudes toward science and technology included all of the items necessary to measure each of the three dimensions of scientific literacy and utilized a national probability sample from which valid generalizations might be made (Miller, 1983). The results revealed that fewer than half of our adult population had a minimal facility with basic scientific terms, while only 40 percent demonstrated a minimal level of competency with science issues.

The situation becomes clearer if we compare scientific literacy with everyday "reading and writing" literacy. (Figure 2) In that context, answering a simple question

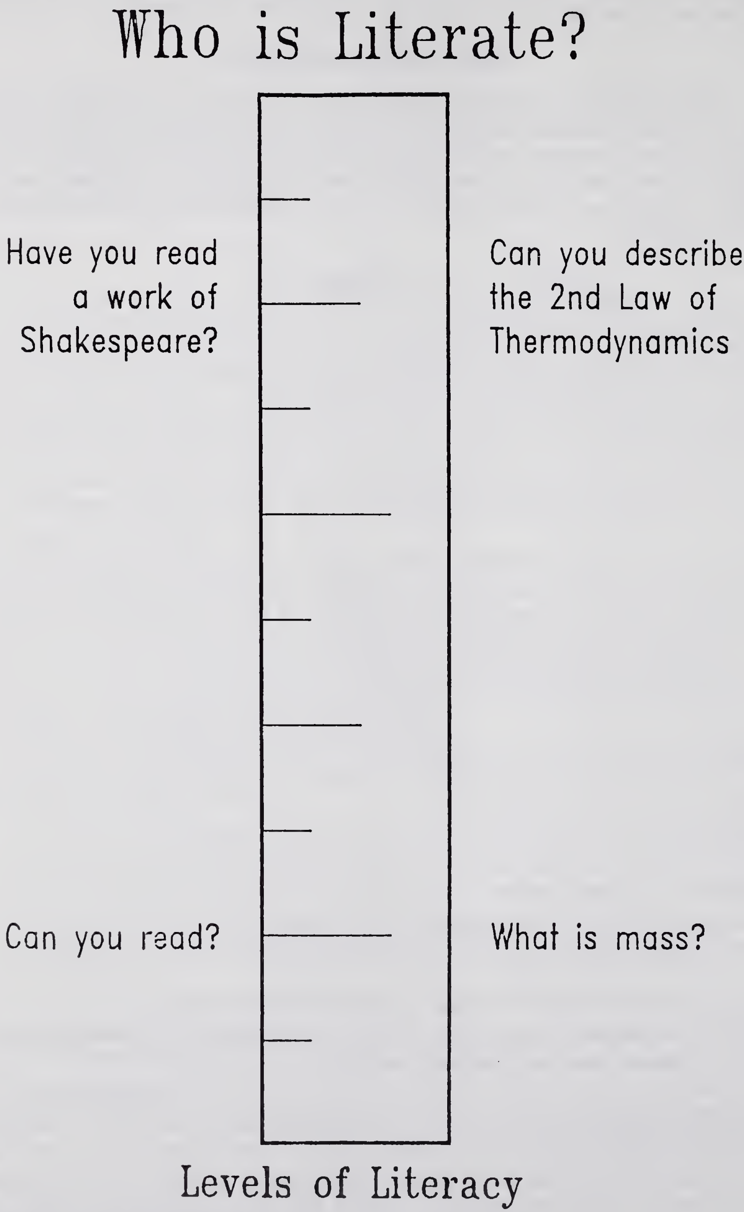

FIGURE 2. Levels of Literacy.

such as "What is mass?" is equivalent to being able to read. At a more sophisticated level, we can equate the ability to read Shakespeare with the ability to describe the Second Law of Thermodynamics. Think for a minute, would our colleagues call us illiterate—if we had never read Shakespeare? Yet, do they apologize for not understanding physics? The situation was dramatized for me several years ago when I was the biology educator for a New York Zoological Society's expedition to the Galapagos. Each participant, lawyer, doctor, journalist, volunteer, was interested in nature, photography, and travel. Although affluent and highly educated, most claimed to be unable to understand science and steered clear of the geological and biological presentations that preceeded each landing. Yet, I was expected to discuss books, arts, and politics with a high degree of literacy and aplomb every evening at dinner. Who is literate?

The results of the National Science Foundation's survey divide the general public into two basic segments. (Figure 3) Approximately 82% of the general public is unat-

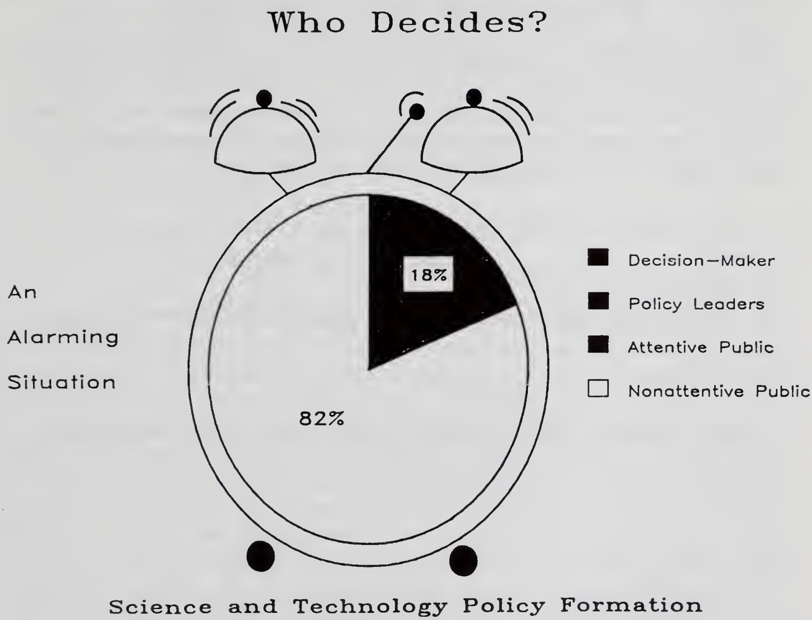

FIGURE 3. Science & Technology Policy Formation.

tentive to scientific and technological issues, while 18% of the public is attentive to science and technology policy formation (Miller, 1983). A smaller proportion of the attentive public are policy leaders and an even smaller proportion are the decision makers. Therefore, the general public has become dependent upon politicians and science journalists, at best, or idealogues and yellow journalists, at worst, to interpret scientific issues. This alarming situation is illustrated by considering the importance of scientific literacy in adjudicating the issues of scientific creationism in our schools. Judge Overton of the U.S. District Court of the Eastern District of Arkansas based his 1982 decision on a definition of what constitutes science. His opinion, which prevented the infusion of scientific creationism into biology courses, illustrates the importance of scientific literacy. He wrote:

> More precisely, the essential characteristics of science are:
> (1) It is guided by natural law;
>
> (2) It has to be explanatory by reference to natural law;
>
> (3) It is testable against the empirical world;
>
> (4) Its conclusions are tentative, i.e., are not necessarily the final word; and
>
> (5) It is falsifiable.
>
> Creation science . . . fails to meet these essential characteristics.
>
> (Overton, 1982, p. 175).

Although a non-scientist, Overton's scientific literacy enabled him to bridge the chasm between the two cultures.

The problem of scientific literacy is compounded by a general lack of literacy concerning technology and computers. (Figure 4) Few traditionalists can distinguish

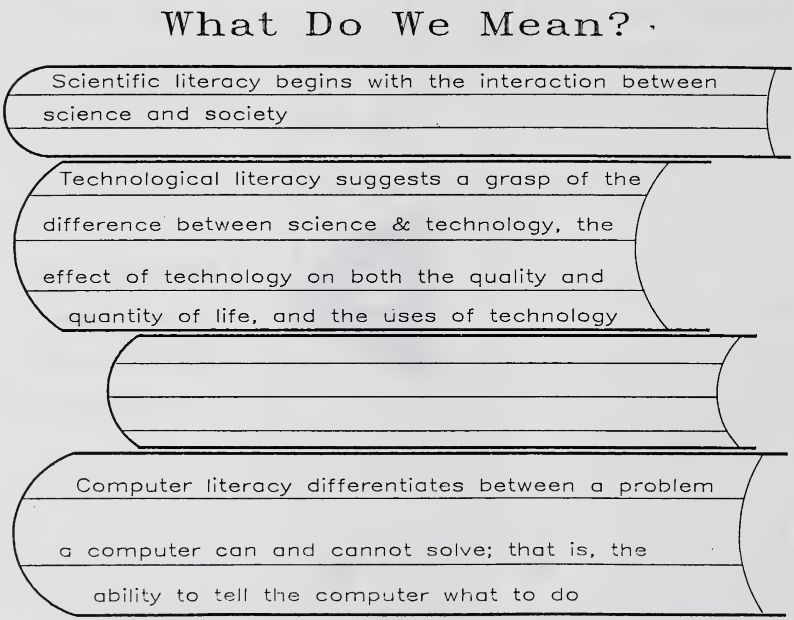

FIGURE 4. Definitions of Scientific, Technological & Computer Literacy.

between science and technology,[1] let alone define technological literacy. And one only has to check on a computerized Visa account to realize that computers "think." However, basic literacy in all three areas will be prerequisites for employment in and understanding of our information-based society. As Frank Press has said,

> Literacy . . . does not mean that all students should be able to draw the structure of DNA. They should, however, have a basic understanding of the world of technology in which they will live and in which a rising proportion will make their living. They should understand what computers actually do and what their limits are. The world of the present decade will use a new language: robotics, CAD, CAM, integrated circuits, and the like. Those who do not understand that language are in for a difficult time.
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> (Press, 1982, p. 1055.)

Who Has Scientific Literacy?

Although scientific literacy has been espoused as an educational goal, little is done to achieve it. As Graubard has written,

> If scientific illiteracy is common today, it is because America's schools and universities permit the condition to exist, indeed perpetuate it. Until a more conscientious effort is made to understand how educational institutions, in collusion with students, tolerate the evasion of science, making science appear an arcane mystery, comprehensible only to a few, necessary only for certain occupations and professions, the true extent of contemporary American educational disingenuousness will never be seen. . . . Modern science is thought to be beyond the intelligence of ordinary children, of whatever class or race. . . . To teach science well, at any level, calls for great skill. To learn science, beyond the most rudimentary level, demands effort, attention, and precision. . . . Why, then, have schools and universities been so lax, so ready to accept illiteracy in science and in other equally demanding subjects? Why, in short, has the student mood been so relaxed for so long? Why does the condition persist today, despite the alarms increasingly sounded about the importance of academic achievement for job security, the growing concern about 'downward mobility' for great numbers of middle-class youth, and the grim employment prospects for those condemned to live in urban ghettos, often forced to contend with racial prejudice as well as with insufficient training? Why do these several conditions—each affecting millions—not produce major political repercussions?
>
> The answer, quite simply, is that these conditions do not produce a 'crisis'; they do not announce an imminent upheaval.
>
> (Graubard, 1983, pp. 239-240.)

Science is avoided, indeed evaded, by most students. Nationally, only about one-sixth of all secondary school students currently take junior and senior courses in high school science and mathematics, and this fraction has remained constant for several years. Even after the recent, well-publicized, science education "crisis," only thirty states require more than one year of science or math for high school graduation. In contrast, Soviet schools require five years of physics, four of chemistry, 5.5 of biology, and five of geography. In the U.S., few students who are not intent on science or engineering careers take science beyond 10th grade biology or mathematics beyond 10th grade geometry, and the dropout rate from science and mathematics beyond the 10th grade level is particularly severe for girls and for minority students. Recent figures indicate that only 9% of our students take one year of physics, 16% one year of chemistry, 17% one year of general science, and 45% one year of biology. Futhermore, the proportion of students enrolled in science courses has declined over the last 20 years. Thus, in effect, at the age of 16 many students deny themselves the opportunity to enter rigorous college level courses in science, mathematics, or engineering. In addition, the majority of students leave high school with neither the basic skills of science and technology nor an understanding of those disciplines.

Unfortunately, this situation continues into college, where fewer than 25% of the students elect science majors, and where non-science majors take few, if any, laboratory science courses. (Figure 5) Our students demonstrate a lack of interest in basic science or in scientific issues while espousing strong opinions on science related issues. (Figure 6) How have they formed such opinions? What evidence have they used? Are they scientifically literate?

Recently, Lafayette and Indiana lost a bid for a multi-million dollar Mitsubishi plant. In commenting on the situation, President Beering noted the lack of language

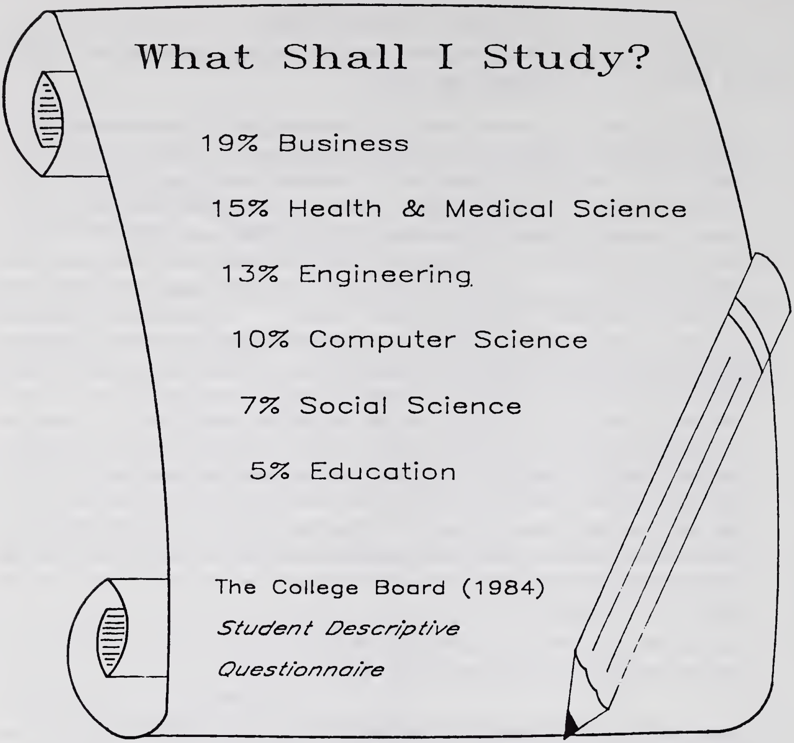

FIGURE 5. Intended Majors of Incoming U.S. College Freshmen (1984).

skills on the part of the Hoosier negotiating team and commented that students believe that they have to select between science and technology or the liberal arts. He stated, "It's not an either/or situation. It's a 'both' and an 'and' situation" (Brameier, 1985, p. 1). The "both" and "and" approach can lead to a scientifically literate population. Indeed, science is central in the liberal education of all students. In the future, "to be scientifically illiterate is to be uneducated" (Phillips, 1985, p. 97).

How to Teach for Scientific Literacy?

Two teacher scientists, Arnold Arons and John A. Moore, have thought and written about educating Americans for scientific literacy. I shall lean heavily on their writings as I search for the "missing link." Both begin with the nature of science and state that science cannot be taught by verbal inculcation; both investigate current science courses and suggest curricular changes; and both describe a scientifically literate person.

Currently, there are two kinds of college courses that purport to cultivate scientific literacy in the non-science student. They are:

* courses which in one quarter, one semester, or even one year attempt to provide insights into the major achievements of science, and
* courses which in an equally restrictive time period focus on a narrow, but topical, area such as eugenics, environment, or energy.

(Arons, 1983, p. 96.)

Who Cares?

Agree Strongly or Somewhat	♂	♀
Government isn't protecting environment	77.6%	82.3%
Government should discourage the use of energy	71.6	78.4
Government should provide national health care plan	56.4	62.3
Abortion should be legalized	54.7	54.8
Marijuana should be legalized	28.4	23.1
Objectives Considered Essential		
Making a contribution to scientific theory	18.0%	11.1%
Helping clean up environment	23.7	18.8

Attitudes of U.S. College University Students
The Chronicle of Higher Education (February 1, 1984)

FIGURE 6. Attitudes of U.S. College/University Students.

Such courses, like Halley's comet, appear briefly, receive rave student evaluations, and vanish rapidly to be followed by newer offerings, which continue to be both ephemeral and evanescent.

In the first category, students, despite the good intentions of the young scientists who usually teach the courses, are invariably subjected to an incomprehensible stream of technical jargon, to a rapid-fired approach, and to an information overload. According to Arons,

> [B]oth the pace and the volume of material preclude any meaningful reflection on the scope and limitations of scientific knowledge or of its impact on our intellectual heritage and view of man's [sic] place in the universe. The 'stream of words' courses have not solved, and will not solve, our education problem, however handsomely illustrated the texts and however liberally salted they may be with allusions to pollution, ethics, energy crises, stellar nucleosynthesis, black holes, and Kafka.
>
> (Arons, 1983, pp. 96 & 97.)

Although such courses try to focus on essentials, in science today's essentials rapidly become tomorrow's trivia. With scientific knowledge doubling every five years, survey courses are dated before they are begun.

Courses in the second category, on the other hand, offer what I call the smorgasbord approach to science—attractive nibbles with little substance. As an undergraduate at the University of Chicago, my son called such courses "cocktail science;" that is, courses which provided the gist for interesting cocktail conversation. In a more serious vein, Arons writes that

> intellectual integrity would demand that students acquire some genuine comprehen-

sion of the scientific concepts, theories, and insights underlying the great topical problem being examined, and that students should not be encouraged to discourse vacuously on matters they essentially do not understand.

(Arons, 1983, p. 97.)

Most philosophers and teachers of science agree that the unique contribution of science in the education of scientists and non-scientists alike is the development of critical thinkers. Such students and citizens are able to distinguish between science and pseudoscience; are able to evaluate evidence; are able to discard old ideas and notions; and, most of all, are able to be moved by reason. How do we plan and teach courses to develop critical thinkers?

Arons suggests that we must move students beyond declarative knowledge (knowledge of facts) to operative knowledge (understanding the source of facts). The following example illustrates the two types of knowledge:

Declarative	*Operative*
The earth revolves about sun	How do we know earth revolves around sun and why do we accept that view when appearances suggest the opposite?

Scientific literacy is only possible with a thorough grasp of operative knowledge in at least one area of science, and critical thinking requires a familiarity with criteria for assessing reasons (especially those concerned with empirical evidence) in several disciplines. (Siegel, 1985).

One suggestion focuses on course content. That is, we should "back off," "slow down", and give students time to follow and absorb the development of a small number of major scientific ideas. For example, a course could concentrate on one or more of the following ideas.

* Why do we believe the earth revolves around the sun? In what context and theory is this statement true?
* Why do we believe that matter is discrete in structure; that is, what is the evidence for the atomic-molecular theory?
* What do we mean by the concept 'electrical charge?' How does the concept originate? Is 'charge' a kind of substance? On what grounds do we believe that there are only two kinds of electrical charge? What (hypothetical) experience would force us to conclude we had discovered a third variety?[2]
* Why do we believe that living organisms have changed over time? What is the evidence?

Another suggestion focuses on pedagogy. Courses to develop scientific literacy should be structured to promote "science as a way of knowing" (Moore, 1983). (Figure 7). At the very least, students should be able to state the problem to be investigated. Second, they should use the common sense approach to make a preliminary "guess" as to what the answer may be. That step is similar to developing a hypothesis by induction and that hypothesis must be testable. Since the data must be verifiable, Moore (1983) suggests that science is a self-correcting way of knowing. Arons concurs with Moore stating that college students need to practice the above modes and that such practice should include opportunities to detect and correct errors.

A third suggestion targets the curriculum. The barriers between the two cultures need to be broken down. As scientists who teach science we need to become more literate and articulate about the societal, historical, philosophical and epistemological aspects of our particular field. Since few of us were trained as generalists, such knowledge

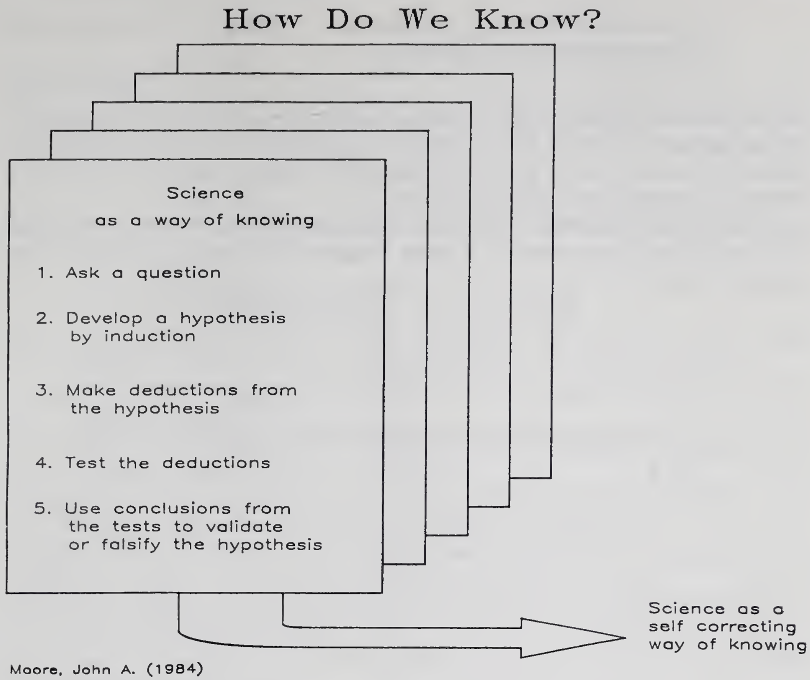

FIGURE 7. Science As a Way of Knowing.

will require deliberate effort. Likewise, instructors in the humanities must stop running from science and see it as an ideal discipline to develop critical thinkers. The techniques proposed will cause frustration; it is easier to tell than to do science. The courses suggested must be viewed as a "raising up" rather than a "watering down" of science; for only with new pedagogy and new content can we help students understand the principles and concepts of science.

What Are the Characteristics of Scientific Literacy?

If we are successful in changing our courses and our methods of teaching, we will find that our students will be able to:

* Recognize that scientific concepts are created by acts of human intelligence.
* Recognize that a scientific concept involves first an idea and then a name and that technical jargon is not science.
* Differentiate between observation and inference.
* Understand the meaning of theory in the scientific context.
* Develop a basic knowledge and understanding in one area of science which permits further learning without formal instruction.
* Recognize the few specific instances in which scientific knowledge changed intellectual history.
* Make decisions on issues concerning science and society.
* Understand the similarity between certain modes of thinking in science and

> other disciplines (history, political science, sociology, and economics); that is, hypothetico-deductive reasoning.
>
> (Arons, 1983).

To develop a scientifically literate population mathematics, science and technology must become part of the core of liberal education. In addition, the science courses in that core must present "science as a way of knowing" in order to move students toward operative knowledge and critical thinking.

In summary, our goal is "savvy" citizens. (Figure 8) For example, a person with street savvy might use probability in penny pitching, discuss statistics in football, and

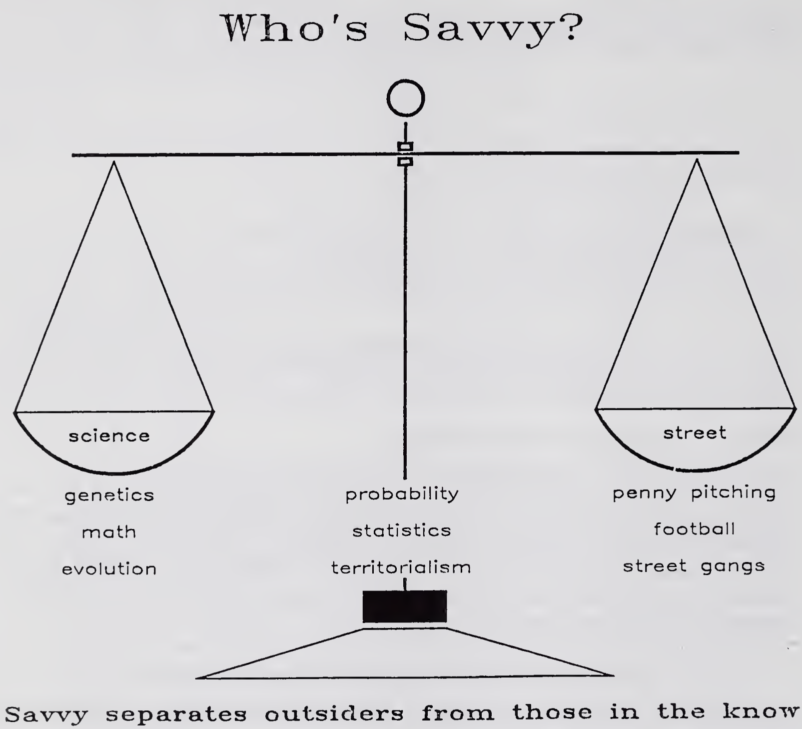

FIGURE 8. Science Savvy.

understand territoriality through street gangs. While someone with science savvy would understand probability in genetics, use statistics in math, and discuss territoriality in evolution.

> By definition savvy citizens are not outsiders in their own society. Rather than being manipulated (or feeling manipulated) by forces beyond understanding and beyond control, the citizen 'in the know' can make the system work.
>
> (Prewitt, 1983, p. 54).

Citizens who have "science savvy" can make the system work for them. They may lead enriched lives; they may hold better, or more permanent, jobs. In any case, their scientific literacy will provide a linkage between the two cultures in our society, enabling them to be savvy citizens.

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Reference Notes

1. For the purposes of this paper, technology will be considered the branch of human experience that people can learn and use with predictable results.
2. The first three examples are taken from Arons, A. B., 1983, p. 98.