

## Assessing nature-of-science literacy as one component of scientific literacy

Carl J. Wenning, Coordinator, Physics Teacher Education Program, Illinois State University, Normal, IL 61790-4560 [wenning@phy.ilstu.edu](mailto:wenning@phy.ilstu.edu)

*It is frequently said that achieving scientific literacy is the main goal of science education. It should therefore seem reasonable that some means would exist for assessing progress toward that goal. Unfortunately, such an assessment instrument does not appear to exist. Perhaps this is due to the fact that scientific literacy has been defined in a multitude of ways and, therefore, it is difficult to determine just what to assess. A concise, mutually agreeable definition of scientific literacy has been an objective for many scientists, educators, and philosophers for the better part of the 20th century, and only recently has there been some degree of convergence in thinking. For the sake of assessing progress toward the goal of achieving science literacy, it might be easier to break unwieldy definitions of scientific literacy into smaller, more manageable components that would be easier to assess. One of the central themes of scientific literacy has almost always been an understanding of the nature of science. This theme has been used to create an assessment instrument as one part of a potential battery of tests to assess progress toward the more general goal of scientific literacy. Such a battery of instruments can provide critical information for assessing gaps in student knowledge, guiding instructional practice, holding schools accountable for achieving specific goals, and determining program effectiveness. Having previously established a framework for assessing nature of science literacy, the author hereby makes available a 35-item Nature of Science Literacy Test (NOSLiT).*

### **Scientific Literacy – The Main Goal of Science Education**

Enhancing the scientific literacy (also commonly referred to as science literacy) of school children has been a goal of science educators for more than a century. Dewey's turn-of-the-twentieth-century calls for the use of experiential learning and inquiry practice was directed toward enhancing the general scientific literacy of school children. He argued that teaching theory should be more closely associated with desired outcomes (1904), and that the best way to get students to become more scientifically aware and informed is through the processes of experiential learning – having students learn science by mimicking the work of scientists. Six years later, Dewey (1910, p. 25) noted, "Science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject-matter." Dewey later (1916, 1938) repeated his calls for reform in teacher preparation and classroom practice. Unfortunately, these calls for reform fell on deaf ears.

After the close of World War II, a new movement to reform science education began to make its appearance. This was due, in large part, to the fact that modern technology employed in winning the war for the Allies was based upon revolutionary discoveries in science. What most readily comes to mind is the scientific research that went into developing the atomic bombs dropped on Hiroshima and Nagasaki, Japan, and development of antibiotics for combating infections. Later, from the mid 1940s through the early 1960s, the evolving stage theory of cognition, and child growth and development following insights of psychologists Kurt Lewin and Jean Piaget took center stage

in the science teaching reform movement. The discussion revolved around such questions as intellectual ability at various developmental levels, and what implications this might have for pedagogy. This reform movement was given a boost in October 1957 with the launch of Sputnik I by the U.S.S.R. Shortly after this earth-shaking event, broad-based work was begun in earnest to change the practice of American science teachers and thereby improve the scientific literacy of American students.

While the "Alphabet Soup" science education projects of the 1960s ostensibly had as their goal improvement in general scientific literacy, a major ulterior motive was the production of more scientists. This helps to explain the participation of so many "hard" scientists in the education reform movement. For instance, Robert Karplus – a physicist who introduced the learning cycle – and Jerrold Zacharias – a physicist who was concerned with promoting intuitive thinking – became key players in the scientific literacy movement. In the first half of the 20<sup>th</sup> century, the practice of many (if not most) science teachers concentrated on merely imparting content knowledge. Pedagogy often consisted of drill and practice, and assessment focused on fact-laden tests. To help break this cycle, large-scale inquiry-oriented curriculum development projects such as BSCS, CHEM Study, SCIS, ESS, PSSC Physics, and ESCP were developed. Unfortunately, by the mid-1970s nearly all of these programs had played themselves out, primarily due to political reasons. The rise and fall of the alphabet soup projects – and the failure of the Sputnik era science teaching reform movement – was well documented in *Schoolhouse Politics: Lessons from the Sputnik Era* (Dow, 1999).

In the early 1980s, a new round of science education reform began sweeping the United States. The National Commission

on Excellence in Education (1983) stated in the implementation section of *A Nation at Risk: The Imperative for Educational Reform*, that the “teaching of science in high school should provide graduates with an introduction to (a) the concepts, and processes of the physical and biological sciences; (b) the methods of scientific inquiry and reasoning; (c) the application of scientific knowledge to everyday life; and (d) the social and environmental implications of scientific and technological development.” For the first time considerable attention was paid to what can be considered a broader form of scientific literacy. In subsequent years, the reform movement that began with *A Nation at Risk* has moved forward as evidenced by such efforts as the American Association for the Advancement of Science’s Project 2061, the National Research Council’s *National Science Education Standards*, and the National Science Teacher Association’s *Scope, Sequence, and Coordination*. This triad of major educational reform bodies, arguably the most important in the present science education reform movement, have as their goal the development of a heightened degree of scientific literacy among school children and, ultimately, the general populace.

Project 2061 was predicated on achieving the goal of scientific literacy. AAAS efforts have subsequently produced two publications, *Science for All Americans* (AAAS, 1989) and *Benchmarks for Science Literacy* (AAAS, 1993) that are widely used by different groups working on science teaching reform at various levels. *Science for All Americans* clearly enunciated this orientation in its key recommendations about how to reform the American science education landscape, “One fundamental premise of Project 2061 is that the schools do not need to be asked to teach more and more content, but rather to focus on what is essential to scientific literacy and to teach it more effectively” (p. xvi). The follow-up publication, *Benchmarks for Science Literacy*, notes, “*Benchmarks* specifies how students should progress toward scientific literacy, recommending what they should know and be able to do by the time they reach certain grade levels” (p. XI).

Both *Benchmarks for Science Literacy* and the *National Science Education Standards* were written to present “a vision of science education that will make scientific literacy for all a reality in the 21<sup>st</sup> century” (NRC, 1996, p. ix). *National Science Education Standards* (NRC, 1996) “present a vision of a scientifically literate populous” (p. 2), and “are designed to guide our nation toward a scientifically literate society” (p. 11). The NRC standards for teacher preparation and classroom instruction are based on the assumption that scientific literacy should be the primary goal of science instruction at the pre-college level. In the section “Goals for School Science,” *NSES* relates four abilities critical to the educational process, and then states that, “These goals define a scientifically literate society” (p. 13). Later *NSES* notes, “An explicit goal of the *National Science Education Standards* is to establish high levels of scientific literacy in the United States” (p. 21).

The National Science Teachers Association’s *Standards for Science Teacher Preparation* “are based upon a review of the professional literature and on the goals and framework for

science education set forth in the *National Science Education Standards* (NSES) (National Research Council [NRC], 1996). The NSES is a visionary framework for science teaching in precollege education, based upon the assumption that scientific literacy for citizenship should be a primary – if not exclusive – goal of science education at the precollege level” (NSTA, 2003, p. 2).

### ***Assessing Progress Toward Scientific Literacy***

With scientific literacy being the “holy grail” of science education, it would seem reasonable that there should exist some means of assessing progress toward that goal. Unfortunately, such an instrument does not appear to exist. None of the late 20th century science reform efforts has resulted in any significant attempt to assess the degree of scientific literacy of students per se, or progress toward achieving that goal. Today, as a result of the standards-based educational reform, “competency” tests in math and science abound and are being given on state, national, and on international levels as represented by such programs as state-mandated No Child Left Behind (NCLB) testing, the National Assessment of Educational Progress (NAEP), and the periodic Trends in International Mathematics and Science Survey (TIMSS). However, these tests are achievement tests, and are not oriented toward assessing scientific literacy in a comprehensive fashion. While some argue that ACT and SAT tests are more geared toward assessing critical thinking and problem solving, these too fall far short of assessing scientific literacy in the broader sense of the concept.

Reflecting the fact that assessments for scientific literacy do not currently exist, the National Research Council has recently published *Systems for State Science Assessment* (NRC, 2005). In response to the NCLB Act of 2002, the National Research Council thereby outlined efforts to assess progress toward achieving scientific literacy. This work by the Committee on Test Design for K-12 Science, outlined “the ideas and tools that are needed to assess science learning at the state level - describing what should be measured and how it should be measured.” The existence of this publication is indicative that the NRC is at least somewhat cognizant of the fact that there is a significant deficiency in this area.

### ***Toward of Definition of Scientific Literacy***

The failure to have an instrument for assessing scientific literacy is probably due to several major reasons: (1) definitions of scientific literacy can incorporate a wide range of types, dimensions, and degrees; (2) a definition of scientific literacy will necessarily be complex if it is to be comprehensive and therefore meaningful; (3) a comprehensive assessment instrument would be of unacceptable length; (4) no single “high stakes” assessment instrument could provide all the information needed by teachers, school administrators, and agencies to make decisions to improve student learning; (5) there appears to be a confusion about educational purpose, teaching methods, and

student outcomes, and (6) no one speaks officially on behalf of the world of scientists, philosophers, and educators who can advance by fiat a universal definition of scientific literacy.

The failure to have a commonly agreed upon definition of scientific literacy is not for the lack of effort. In fact, a precise definition of scientific literacy has been an objective for many scientists, educators, and philosophers for the better part of the 20th century. Unfortunately, this problem of defining scientific literacy in a mutually agreeable fashion has dogged the science education reform movement from the outset, and the situation is only marginally improved today as a review of definitions will show. Though the process of giving meaning to the phrase “scientific literacy” might be thought of as one that is deeply philosophical that might be methodically and systematically approached, this has not been the case. Work to define the meaning repeatedly has been initiated from the beginning by scientists, educators, and philosophers of science using an approach that Benjamin Shen (1975) has referred to as “ordinary language philosophy.” This approach has led to more than a half century of haphazard progress toward a commonly accepted definition of scientific literacy.

According to Rodger Bybee (1997), James Bryant Conant first used the term “scientific literacy” in 1952 writing for *General Education in Science*, a work edited by I. B. Cohen and Fletcher Watson. Quoting from Bybee, “Such a person might be called an expert in judging experts. Within the field of his experience, he would understand the modern world; in short, he would be well educated in applied science though his factual knowledge of mechanical, electrical, or chemical engineering might be relatively slight. He would be able to communicate intelligently with men who were advancing science and applying it, at least within certain boundaries. The wider his experience, the greater would be his scientific literacy” (Bybee, 1997, p. 47). As might be expected with initial definitions, the meaning of this passage is vague. It is not clear from this definition what a person needs to know, be able to do, and what sort of habits of mind and attitudes one needs to possess in order to be scientifically literate.

Following the work of Conant, science education philosopher Paul DeHart Hurd (1958) defined scientific literacy in relation to a general knowledge about science and its applicability to the social environment. Science is so important, he argued, that no aspect of life – political, social, economic, personal – should be considered without reference to it. Hurd went a bit farther than Conant in defining scientific literacy when he wrote, “There is the problem of building into the science curriculum some depth and quality of understanding. It is essential to select learning materials that are the most fertile in providing opportunities for using methods of science. Further efforts are required to choose learning experiences that have a particular value for development of an appreciation of science as an intellectual achievement, as a procedure for exploration and discovery, and which illustrate the spirit of scientific endeavor” (p. 14-15). As to the relationship between science and society Hurd continued, “Today most aspects of human welfare and social progress are in some manner

influenced by scientific and technological innovations. In turn, scientific knowledge establishes new perspectives for reflection upon social progress. The ramifications of science are such that they can no longer be considered apart from the humanities and the social sciences. Modern education has the task of developing an approach to the problems of mankind that considers science, the humanities, and the social studies in a manner so that each discipline will complement the other” (p. 15).

It should be noted that this statement came shortly after the October 1957 launch of Sputnik I – the small Soviet satellite that was the first man-made object to orbit the earth – which focused the spotlight of public attention on scientific literacy. If nothing more, Hurd made “scientific literacy” the bywords of the science reform movement of the 1960s, and was instrumental in moving the term into the mainstream of modern science education parlance. Nonetheless, the focus of the reform movement up to this point in time had been on creating a few scientifically literate individuals so that they might become the scientists and engineers of the future. Scientific literacy for the masses was still on the horizon.

Two years after Hurd, Fred Fitzpatrick edited a short work titled *Policies for Science Education* (Fitzpatrick, 1960) on behalf of the Science Manpower Project started in 1956 at Teachers College, Columbia University. In his commentary Fitzpatrick noted that the ongoing science education reform movement should not focus so narrowly on creating scientists and engineers, but that science education reform should extend to all citizens. He wrote, “In considering the need for scientific manpower, however, we should not lose sight of the fact that no citizen, whether or not he is engaged in scientific endeavors, can be literate in the modern sense until he understands and appreciates science and its work... If the zeitgeist is to be favorable to the scientific enterprise, including both academic and industrial programs, the public must possess some degree of scientific literacy, at least enough to appreciate the general nature of scientific endeavor and its potential contributions to a better way of life” (p. 6).

Physicist Polykarp Kusch (1960), calling for a grander view of the spirit and nature of science, attempted to characterize scientific literacy for all citizens when he wrote, “The attempt, honestly undertaken, almost certainly will lead to scientific literacy if not to profound knowledge. It may lead to a high respect for the methods, the integrity, the spirit, and the results of science. That citizen who respects the structure of science, who is able to view the results of science as a critical and careful statement of man’s best knowledge of the behavior of nature is, to my mind, better able to participate effectively in the conduct of our national and international affairs – indeed in every aspect of our life” (p. 199).

Adding his comments to the growing belief that scientific literacy meant more than a familiarity with a large collection of scientific facts, Philip G. Johnson (1962) noted that, “some goals of science education have become so dominant that the pursuit of other important goals has been severely inhibited; often there has been a failure to recognize adequately the abilities and needs

of the general citizen, and thereby skirt the goal of scientific literacy” (p. 244). Scientific literacy, he argued, must also include particular attitudes and values, particularly those “habits of mind” that come from the nature of science itself.

Alma Wittlin (1963), writing in the elementary school publication *Science Education*, outlined the requirements of scientific literacy, and connected them with developmental psychology, science teaching, and curriculum development. Scientific literacy, she noted, must include a broad base of information known in depth, an understanding of the relationships between the various scientific fields, a knowledge of the contribution made by science to human welfare, and an appreciation of the ventures undertaken by scientists in the process of discovery. She also went on to argue that this characterization must encompass two areas of endeavor, both technology and the underlying science, because these two make up the environment that humans encounter on a daily basis.

That same year, Morris Shamos, a noted science educator, began a campaign arguing that scientific literacy of the general population so defined is essentially unachievable (Shamos, 1963, 1995). He argued that societal scientific literacy among the masses is something achievable only in a humanistic way. That is, science educators should strive for creating a form of scientific literacy that is essentially humanistic – feeling comfortable talking with others about science in non-technical terms. Such individuals would know the difference between science and technology, and understand the major conceptual schemes of science – the atomistic form of matter, conservation laws, germ theory, heredity, and the nature of science as examples.

The National Science Teachers Association (NSTA) also entered the discussion of the character of scientific literacy in 1963. Robert Carlton (1963) surveyed scientists and science educators in pursuit of a suitable characterization of scientific literacy, and in an effort to determine how to arrive at a greater scientific literacy among school children. Only a very few respondents identified with the science and society theme as part of the definition; a vastly greater number of respondents saw scientific literacy as a knowledge of certain content areas in science, and a limited understanding of scientific methods and accomplishments. A year later, the NSTA (1964) formally declared in its publication *Theory into Action* that the main goal of science education was the creation of scientifically literate individuals. The scientifically literate individual would be one who, “knows something about the role of science in society and appreciates the culture conditions under which science survives, and knows the conceptual inventions and investigative procedures” (p. 9).

Charles Koelsche (1965) functionally characterized scientific literacy in yet another way that has been echoed by others over the years (Hirsh, 1987; Hazen & Trefil, 1991). Koelsche saw scientific literacy as an accumulation of knowledge and skills required to understand science as presented by electronic and print media. He identified 175 scientific principles and 693 vocabulary words that commonly appeared in a sample of magazines and newspapers. Science teaching, he suggested,

should focus on these principles and terms because they form the crux of what every person should know to be able to effectively understand and communicate concerns about scientific issues.

With the arrival of the mid 1960s, the discussion about the nature of science literacy had begun to mature and it was clear that there were certain consistent trends of thought in the numerous definitions that had been put forth. In a meta-analysis of some 100 articles, Milton Pella, George O’Hearn, and Calvin Gale (1966) summarized how the authors defined scientific literacy. The six most common defining elements of the term, noted with number of referents and ranked from most frequently cited, were:

- interrelations between science and society (67)
- ethics of science (58)
- nature of science (51)
- conceptual knowledge (26)
- science and technology (21)
- science in the humanities (21)

Pella (1967) used the results of this study to synthesize an inclusive definition of scientific literacy. He stated that the scientifically literate individual should: understand in interrelationships between science and society, understand the methods and processes of science, have a knowledge of fundamental science concepts or conceptual schemes, and understand the relationships between science and the humanities or look upon science as a part of the humanities.

In their earlier meta-analysis, Pella, O’Hearn, and Gale (1966) noted that there were several major goals associated with teaching for scientific literacy. Among them were preparation of scientists and engineers, the preparation of technicians, and preparation of the general populace. This was one of the earliest referents to the possibility of more than one type of scientific literacy. Four years later, Donald Daugs (1970) highlighted these distinctions, and noted that scientific literacy was not an all or nothing proposition but, rather, was a matter of degree. As Bybee (1997) later noted, “This insight – expanding the definition of scientific literacy – was crucial in later discussions, from various perspectives, of a definition” (p. 55).

A year after Daugs’ pronouncement, the NSTA (1971) published a notable declaration dealing with the goals of science teaching. “The major goal of science education is to develop scientifically literate and personally concerned individuals with a high competence for rational thought and action” (p. 47). The NSTA characterized the scientifically literate individual as one who uses science knowledge, skills, and dispositions in making day-to-day decisions, who understands the relationships between science and technology and their relationship to society including historical, interpersonal, and economic dimensions. For the first time the history of science and social issues were given a place of significance in a definition of scientific literacy.

After the publication of NSTA’s 1971 declaration, Michael Agin working with Pella (Agin & Pella, 1972) began to examine the interrelationships of science and society using a socio-

historical approach, thus leading to a broader conception of scientific literacy still. Agin (1974) conducted a meta-analysis of the literature dealing with the concept of scientific literacy. On the basis of his findings, he proposed six broad categories that comprised the conceptual framework of scientific literacy as most writers saw it: science and society relationships, the ethics of science, the nature of science, the concepts of science, science and technology, and science and the humanities – thus mirroring the findings of Pella (1967) writing seven years earlier. Agin's contribution is significant, however, in as far as it went to provide aid in developing interdisciplinary teaching units, describing each, and providing examples of concepts and ways to plan and teach them.

During the mid-1970s Victor Showalter (1974), reporting on collegial work and writing in the newsletter of the Unified Science Education program, gave a general overview of scientific literacy when they wrote, "In many ways, scientific literacy represents the goal of a liberal or general education in science. Ideally, each citizen has made and continues to make satisfactory progress toward this goal" (p. 1). This working group summarized and provided rationales for seven "dimensions" that for them constituted scientific literacy: nature of science, concepts in science, processes of science, values of science, science and society, interest in science, and the skills of science. Each of these dimensions was characterized. For instance, under the nature of science dimension, they listed such terms as "tentative" and "public" and "replicable." Again, scientific literacy was perceived by these authors to be a matter of degree along the seven dimensions.

The year 1975 saw the beginning of the Science-Technology-Society (STS) emphasis when Paul DeHart Hurd (1975) restated his scientific literacy theme in *Science, Technology, and Society: News Goals for Interdisciplinary Science Teaching*. Hurd perceived that an integration of the sciences was at the heart of meaningful teaching for scientific literacy as evidenced by his statement, "We have little hope of resolving population, food, health, water, pollution, and many other problems of human concern unless we can relate disciplines and teach them in an integrative mode" (p. 30). Benjamin Shen (1975) took the social context of scientific literacy even farther when he presented the ideas that there were several types of "scientific literacy," each with their own attendant aspects. He described the need for teaching science in a real world context. He noted that to this end there were three types of scientific literacy – practical, civic, and cultural – each with its own audience, content, format, and objectives. To Shen, practical scientific literacy was composed of that knowledge and skill which allowed one to find solutions to those human problems cited by Hurd. To this end Shen wrote, "The most basic human needs are health and survival; much of practical scientific literacy has to do with just those needs" (p. 27). Shen's civic scientific literacy was characterized by an ability of the citizenry to bring "common sense to bear" in making "considered" decisions that relate to public policy. Shen's cultural scientific literacy dealt with human motivation to know something about "science as a major human achievement." With

Shen's efforts, the character of the discussion began to change from the dimensions and degrees of scientific literacy, to types of scientific literacy, foreshadowing additional definitions of scientific literacy.

During 1976 Michael Agin organized a symposium dealing with scientific literacy at the National Association of Research in Science Teaching (NARST) meeting at which George O'Hearn (1976) offered a definition of scientific literacy that can be summarized in four points: (a) basic scientific knowledge, (b) the nature of science, (c) the processes of science, and (d) the social and cultural implications of science. During that same year, Milton Pella (1976) attempted to write an operational definition of scientific literacy using a library metaphor to characterize how science educators should think of scientific literacy. To Pella, "a scientifically literate citizenry understands some of the knowledge library of science, knows some of the limitations and potentials of the contents of the library, knows how and when to apply the knowledge theory, knows where the contents of the library came from, and knows the regulatory principles involved in knowledge production and use" (p. 99). He also decried the indiscriminate use of ill-defined terms and noted that such use can only serve to confuse the issue. What was needed was a more precise definition still. Perhaps more importantly, however, Pella sounded a call for broadly applied standards in science education that might lead to a scientifically literate citizenry. These standards would, by their promulgation, serve to give an even better operational definition to scientific literacy.

In April 1983, the National Commission on Excellence in Education (NCEE) published a report that had a major national impact on teaching for scientific literacy. *A Nation at Risk: The Imperative for Educational Reform* (NCEE, 1983) drew widespread attention to and criticized the failure of American science teachers to educate students in a way that is appropriate to the needs of the rapidly changing technological society of the 1980s and beyond. According to the Commission, low and declining student achievement scores, along with functional illiteracy of a significant portion of U.S. high school students, was pegged to economic and defense risks. The Commission quoted science educators who claimed that the nation was "raising a generation of Americans that is scientifically and technologically illiterate" (Paul DeHart Hurd, p. 10). It also drew attention to the claim that there was "a growing chasm between a small scientific and technological elite and citizenry ill informed, indeed uninformed, on issues with a science component" (John Slaughter, p. 10). While drawing attention to deficiencies in American school education, the Commission outlined what it perceived scientific literacy to be. High school graduates would be adequately educated – scientifically and technologically literate – if they knew "(a) the concepts, laws, and processes of the physical and biological sciences; (b) the methods of scientific inquiry and reasoning; (c) the applications of scientific knowledge to everyday life; and (d) the social and environmental implications of scientific and technological development" (p. 25). The statements found in *A Nation at Risk* had an immediate

and lasting impact on the thinking of the country, and started the nation on a movement toward national standards that would come to conceptualize and embody the operational meaning of scientific literacy. Still, a decade would pass before this would come to the fore.

During the spring of 1983, the journal of the American Academy of the Arts and Sciences (AAAS), *Daedalus*, dedicated an entire edition to the question of scientific literacy in which a number of influential articles appeared. Jon Miller (1983) reported on his study of scientific literacy among the general populace. In a telephone interview of more than 2,000 persons he assessed the public's knowledge of science along three dimensions: scientific processes, basic scientific term recognition, and science policy issues. When all three aspects of scientific literacy are considered at once, less than 7% of the U.S. populace can be considered to be scientifically literate at even the lowest level of the definition – recognition of scientific terms and concepts. In that same issue, Arnold Aarons (1983) characterized the scientifically literate person, and suggested instructional strategies that might be used to achieve scientific literacy among the general population that were based upon the use of learning cycles. The emphasis, Aarons argued, should be on helping students establish an operative knowledge of science rather than merely a declarative knowledge.

Later in 1983 the National Science Board (NSB) released an educational report titled *Educating Americans for the 21st Century* (NSB, 1983) in which it was stated, “students who have progressed through the nation’s school system should be able to use both the knowledge and products of science, mathematics, and technology in their thinking, their lives, and their work. They should be able to make informed choices regarding their own health and lifestyles based on evidence and reasonable personal preferences, after taking into consideration short- and long-term risks and benefits of different decisions. They should be prepared to make similarly informed choices in the social and political arenas” (p. 45).

Shortly thereafter, Morris Shamos (1984) began an effort to discredit what he perceived as the rhetoric of the scientific literacy reform movement. He argued that the goal of general scientific literacy was unachievable, and that efforts to achieve real reform through technological literacy would be more appropriate and more readily realized. He argued that technological literacy is an “easier target to hit” because “one does not need to understand the ultimate causes of things to appreciate their ends and uses” (p. 33). If nothing more, Shamos’ criticisms of the scientific literacy reform movement made science educators and philosophers take pause and reflect on the general direction of the reform movement.

In 1987, the National Research Council released its report *Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12*. The authors of the report, Richard Murnane and Senta Raizen (1988), characterized their understanding of scientific literacy. According to these authors, scientific literacy had several dimensions that encompassed the nature of the scientific worldview, the nature of the scientific

enterprise, scientific habits of mind, and the role of science in human affairs (p. 16). Science is seen as a set of interconnected ideas whose themes permeate the understanding of the world. There is no such thing as “the scientific method,” as many different approaches can be and are used to derive scientific knowledge. These themes include conceptual schemes such as evolution; theories and models such as gravitation, and specific concepts such as energy, scale, and cycles. The scientific enterprise is comprised of ethics and values, and is empirical and theoretical by nature. Scientific knowledge, though tentative, derives from a consensus of the scientific community. Characteristic of scientific habits of mind are use of the scientific methodologies and critical thinking.

In 1989, the AAAS sponsored a forum to deal with the question of scientific literacy. Prior to the beginning of that forum, the AAAS conducted a survey of scientists, science educators, schoolteachers, and policy analysts, in which they were queried about the meaning of scientific literacy. The respondents ranked fifteen capabilities and attitudes that they felt were of importance to the definition of scientific literacy, and characteristics of those graduating from high school. The top five characteristics were determined to be the following:

- Read and understand science articles in the newspaper.
- Read and interpret graphs displaying scientific information.
- Engage in scientifically informed discussion of a contemporary issue.
- Apply scientific information in personal decision making.
- Locate valid scientific information.

In a compendium of works based upon the AAAS forum, Audrey Champagne and Barbara Lovitts (1989) wrote an article in a forum volume titled *Scientific Literacy: A Concept in Search of a Definition*. In this article the authors examined the barriers – perceived and real – that hindered the creation of a consensus defining the meaning of scientific literacy. They drew attention to a confusion of educational purposes, specified course content, instructional methods, and student outcomes. These elements are often intermingled in discussions of scientific literacy precluding a meaningful definition. Champagne and Lovitts also contrasted the top five ranked items in the pre-forum survey with the lowest: defining scientific terms, describing natural phenomena, providing explanations for science concepts, and assessing scientific methodologies. The authors went to the trouble of showing evident conflicts between the highest and lowest ranked elements, and made that argument that scientific literacy must by its very nature be holistically defined.

The end of the decade of the 1980s also witnessed the beginning of Project 2061 along with its flagship work *Science for All Americans* (Rutherford & Ahlgren, 1989). This work summarized the meaning of scientific literacy along the lines of knowledge, skills, and dispositions indicating what all students should know and be able to do if they are to be scientifically literate. “*Science for All Americans* is based on the belief that the scientifically literate person is one who is aware that

science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge in scientific ways of thinking for individual and social purposes” (p. 4). Though not without its weaknesses, Roger Bybee, noted science educator and “historian” of the scientific literacy reform movement, characterized *Science for All Americans* as, “one of the most comprehensive and innovative statements of scientific literacy in the history of science education” (p. 64). Bybee was quick to point out the weaknesses of Project 2061 standards, attacking primarily “an underemphasis on knowledge and an underemphasis on inquiry and design abilities” (p. 64).

Robert Hazen and James Trefil (1991) took a much narrower approach to defining scientific literacy when they wrote *Science Matters: Achieving Scientific Literacy*. Hazen and Trefil’s definition of scientific literacy was based on the need of the general public to comprehend science matters, “What non-scientists so need is the background to grasp and deal with matters that involve science and technology. It is this ability to understand science in its day-to-day context that we propose to call scientific literacy” (p. 44). With the end in view of defining scientific literacy operationally, the authors indicated that the general populace should be first and foremost familiar with the “most basic principle of science,” that being that the universe is regular, predictable, and quantifiable. The authors also felt that the masses should be familiar with the principles shared by all sciences, those being the central laws of physics:

- Newton’s laws governing force and action
- The laws of thermodynamics governing energy and entropy
- The equivalence of electricity and magnetism
- The atomic structure of matter

Vocabulary, facts and certain basic principles of each of five different disciplines (physics, chemistry, biology, astronomy, geology) should serve as the basis of producing a scientifically literate public. The general principle to be employed can be simply stated, “If you want people to know something, tell them.”

Two similar defining moments for scientific literacy came about during the years immediately following the work of Hazen and Trefil with the publication of the NSTA’s *Scope, Sequence, and Coordination of Secondary Science* (1992), and Project 2061’s *Benchmarks for Science Literacy* (AAAS, 1993). Both publications emphasized the defining elements of scientific literacy for high school students, and were heavily skewed toward emphasizing content knowledge as an essential component of achieving scientific literacy.

Morris Shamos (1989), the 1967-68 president of the National Science Teachers Association, writing in the 1989 AAAS scientific literacy forum volume, characterized the many dimensions of scientific literacy in the context of educating

elementary school children. Shamos reflected on E. D. Hirsh’s 1987 popular work *Cultural Literacy* – a book that provided a listing of “what every American needs to know” in order to be culturally literate. The book provided some 5,000 “essential names, phrases, dates, and concepts” that would later serve as the basis for Shamos’ definition of “cultural scientific literacy.” In 1995, with the publication of *The Myth of Scientific Literacy*, Shamos moved on to define higher levels of scientific literacy including “functional scientific literacy” and culminating with “true scientific literacy.” Shamos characterized the three forms of scientific literacy in the following fashion:

- Cultural Scientific Literacy – An understanding of basic background information and vocabulary, especially that shared by literate people. This form of scientific literacy is the level achieved by most adults who believe they are reasonably literate in science. These people recognize many of the science-based terms used by the popular media, which is generally their only source of science information as adults. Periodic exposure to science through the popular press probably provides them with some measure of comfort that they are not totally illiterate in the area of science.
- Functional Scientific Literacy – This understanding builds upon definition of cultural scientific literacy and requires, in addition, the ability to effectively communicate using the basic terms, concepts, and relationships of science. To be functionally literate a person would be familiar with “some of the simple everyday facts of nature” such as the concepts of Earth’s orbital and diurnal motion, eclipses of the sun and moon, the sun as a source of energy, the greenhouse effect, the origin of the oxygen that we breath, and the effects of pollution. Perhaps 40% of the population has attended this level of scientific literacy according to Shamos.
- True Scientific Literacy – At this level the “truly” scientifically literate person will know not only content knowledge of science, but also understand the scientific process whereby that knowledge has been developed. The person will understand the importance of observation and experimentation in science, and will be capable of questioning, using logic for induction and deduction, relying upon evidence, and having a proper understanding of the nature of science. This would also include a basic understanding of the history, values, and assumptions of science. Perhaps only 4% or 5% of the U.S. population ever achieves this level of scientific literacy, and almost all of them will be either scientists or professionals.

The National Research Council released the *National Science Education Standards* in December 1995 (NRC, 1996). This publication culminated nearly five years of work in which some 40,000 scientists, educators, business CEOs, school administrators, and science philosophers collaborated to define comprehensively the nature of science literacy and strategies to be used to achieve it. Because a systems approach was utilized, not only did the *Standards* deal with content, but they also

dealt with five additional domains: teacher training, teaching, professional development, science programs in the schools, and systems of delivery, all of which were oriented toward the goal of improving science education and encouraging students to achieve higher degrees of scientific literacy. The vision for general scientific literacy enunciated in the *Standards* sees students becoming scientific literate as a result of participating in inquiry-oriented activities and thereby developing a fundamental understanding of the basic concepts of science and technology as they relate to both the individual and society. The elements of scientific literacy fall into six categories according to the *NSES*:

- science as inquiry
- science content
- science and technology
- science in personal and social perspectives
- history and nature of science
- unifying concepts and processes

Rodger Bybee (1997), writing in *Achieving Scientific Literacy: From Purposes to Practices*, proposed a multi-dimensional framework for defining the degrees of scientific literacy. His taxonomy contained the following elements: Nominal Scientific and Technological Literacy (individual familiar with terms of science and technology, but retains misconceptions and has token understanding of science concepts; little real understanding); Functional Scientific and Technological Literacy (individual can work with vocabulary as evidenced by reading and writing about scientific and technological matters; understands larger conceptual schemes, but has token understanding of the associations); Conceptual and Procedural Scientific and Technological Literacy (understands the “part and the whole” of science and technology disciplines, can work with major conceptual schemes; understands the structure of the discipline and knows how it can be used to gain new knowledge); and Multidimensional Scientific and Technological Literacy (individual understands the essential conceptual structures of science and technology; includes understanding of history of the disciplines and the nature of science generally; understands the relationships between the disciplines and the whole of science and technology to society). Though a universal consensus on the definition of scientific literacy does not yet exist, it would appear to have the following basic components given by Bybee (1997, p. 68):

- Scientific literacy is a metaphor referring to the purpose of science education.
- Scientific literacy emphasizes a general education orientation.
- Scientific literacy expresses norms or standards for science education programs, methods, and assessments.
- Scientific literacy illustrates different perspectives in science education.
- Scientific literacy represents a continuum of understandings.

- Scientific literacy incorporates multiple dimensions.
- Scientific literacy includes both science and technology.

Clearly, any definition that operationally characterizes scientific literacy by expanding on the above basic components must necessarily be complex. Whether or not Bybee’s characterizations add anything to the definition of scientific literacy will be for future generations to judge.

At the present time there appears to be a growing consensus on the meaning of scientific literacy that began in 1952 and continued until quite recently as evidenced by *Science for All Americans* and the *National Science Education Standards*. These latter definitions tend to have converged on a multidimensional or true form of scientific literacy that incorporates content knowledge (vocabulary, facts, and concepts), process skills (manipulative and intellectual), dispositions (attitudes and behaviors), science-technology-society relationships, and the history and nature of science. For instance, Project 2061’s *Science for All Americans* defines scientific literacy thusly, “Scientific literacy – which encompasses mathematics and technology as well as the natural and social sciences – has many facets. These include being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes” (p. 20).

According to the *National Science Education Standards*, “Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities. In the *National Science Education Standards*, the content standards define scientific literacy. Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A scientifically literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately” (p. 22).

One of the most recent summaries of the nature of scientific literacy comes from the National Research Council. In *Systems for State Science Assessment* (2005, p. 38-39), the authors suggest a very pragmatic definition of science literacy based on



implications of state testing related to the No Child Left Behind Legislation. “Three elements [of science literacy] are commonly found in most state science standards:

- knowledge of science content,
- understanding science as a way of knowing, and
- understanding and conducting scientific inquiry.

Other aspects of science literacy are also important, but they are not included in this discussion because they are not often mentioned in state science standards or assessment. These include, among other things, the history of science, scientific habits of mind, science in social and personal perspectives, and the nature of the scientific enterprise.”

Despite this general convergence and any claims to the contrary, scientific literacy has yet to be clearly and consistently defined. As a result, these vague, incomplete, and even competing definitions of scientific literacy have made assessment of progress toward the goal of scientific literacy difficult to achieve. Admittedly, the AAAS, NRC, and NSTA have made great strides toward operationally defining scientific literacy as far as content knowledge is concerned. Still, these definitions of scientific literacy are not comprehensive. For instance, none of these current national projects goes so far as to include intellectual process skills or scientific dispositions as part of their operational definitions of scientific literacy. With only a general national convergence on what it means for a student to be scientifically literate, it will be impossible to develop an assessment instrument to assess scientific literacy or progress toward that goal. Rather than waiting interminably for a mutually-agreeable definition of scientific literacy to evolve, perhaps it would be easier to break the larger, unwieldy task of assessing scientific literacy into smaller, more numerous, but manageable subtasks and developing a battery of assessment instruments that, by their very nature, would operationally define scientific literacy.

### ***The Importance of a NOS Literacy Assessment Instrument***

As can be seen from the review of the historical development of a definition for scientific literacy, one of the central themes has almost always been an understanding of the nature of science. This topic can be used as one step in the journey toward assessing scientific literacy in a more comprehensive fashion. The nature of science is one of the “big ideas” about which science instruction can be organized. The NRC states that, “Organizing standards around big ideas represents a fundamental shift from the more traditional organizational structure that many states use in which standards are grouped under discrete topic headings. A potentially positive outcome of a reorganization in state standards from discreet topics to big ideas is a shift from breadth of coverage to depth of coverage around a relatively small set of foundational principles and concepts. Those principles and concepts should be the target of instruction so that they can be progressively refined, elaborated, and extended over time” (NRC, 2005, p. 3).

In addition to serving as an operational definitional and an organizing principle for science instruction, a nature of science (NOS) literacy assessment (as part of a battery of scientific literacy assessments) could have a significant impact on both curriculum design and instructional practice. For instance, assessments and their frameworks provide important data required for informed decision making, for holding schools accountable for meeting achievement goals, and for determining program effectiveness. Additionally, such assessments and their associated frameworks can help classroom teachers, school administrators, and educational agencies to exemplify their goals for student learning. All this can be achieved without awaiting a comprehensive definition of the term “scientific literacy.”

The No Child Left Behind Act of 2002 requires that all 50 states develop challenging goals in science and assess student progress toward those goals. The required assessment in science must be in place for the 2007-2008 school year. States are now working toward developing their responses to the Federal mandate. The problem before them is to prepare and implement quality science assessments by the deadline. In an effort to provide assistance with this effort, the National Science Foundation asked the National Research Council to formulate guidelines for this work. The NRC responded by producing *Systems for State Science Assessment* (NRC, 2005). This work was predicated on the fundamental position of the *National Science Education Standards*: scientific literacy should be the goal for all K-12 science education. Any science assessment should therefore include not only content knowledge assessment, but also the critically important idea that it is important “...for students to understand science as a specific way of knowing...” (p. 1). This, too, requires that students have an understanding of the nature of science.

### ***Nature of Science Literacy Test (NOSLiT)***

Authors have developed tests to assess novice and expert understanding of the nature of science. Of particular note is the VNOS questionnaire – *Views on the Nature of Science* – that comes in three versions (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The difficulty with VNOS is that all three versions of the test consist only of open-ended questions to which there are no right or wrong answers. These questionnaires are designed to adduce student perspectives on the nature of science stemming from a rather limited NOS framework. While such questionnaires can be powerful tools in determining what students think in detail about a limited number of topics (7 in version B and 10 in version C), these questionnaires are not based on comprehensive NOS framework, they are difficult to administer and score with large populations, and are not geared toward assessing knowledge about the nature of science per se.

The author introduces here a 35-item assessment instrument, the *Nature of Science Literacy Test (NOSLiT)*, that can be used, in part, to measure student understanding of the nature of science and thereby track progress toward the more elusive goal of achieving scientific literacy. Eight steps were utilized in the development of

*NOSLiT* following the general procedures outlined by DeVellis (1991). The first step was to develop a framework that clearly defines what it is that is being measured. The framework for *NOSLiT* was independently developed and then detailed in an article by the present author (Wenning, 2006). The framework operationally defines what constitutes NOS literacy at a level appropriate to the understanding of a high school science student. According to the author, individuals who are NOS literate will “possess knowledge of the content and history of at least one science discipline, plus knowledge of associated scientific nomenclature, intellectual process skills, rules of scientific evidence, postulates of science, scientific dispositions, and major misconceptions about NOS” (p. 4). Specifications for each of these areas were then given by providing numerous examples of expected knowledge or understanding. This framework gave a clear statement about what needed to be included in the assessment that came to be based upon it. The framework was reviewed several physics teaching majors, scientists, educators, and philosophers of science for completeness, clarity, and to provide a reasonable certainty of validity.

An item pool was then generated for possible inclusion in the assessment instrument. Each item consisted of a multiple-choice question with four possible answers and true-false questions with only two possible answers. One or more questions were generated for each of the specifications presented in the framework. A team of six reviewers consisting of senior level undergraduate physics teacher education majors then reviewed the items for clarity, accuracy, reading difficulty, and redundancy. Each of these reviewers had a high level of understanding of the nature of science as determined by multiple and varied assessments completed as part of their physics teacher education course work at Illinois State University. These students carefully aligned each of the test questions with the specifications in the framework article to help ensure comprehensive coverage of and agreement with the defining framework.

An initial pilot test consisting of 30 questions was administered to 386 high school physical science students enrolled in six different central Illinois high schools during February 2006. The population generally consisted of freshmen enrolled in introductory lab science or general science courses, sophomores enrolled in chemistry courses, and juniors and seniors enrolled in physics courses. The range of scores on the pilot test was 0 to 26. The test mean was 15.74 (52.5%) with a standard deviation of 4.13 and a standard error of measurement of 2.37. The KR20 reliability coefficient was an unacceptably low 0.67. An analysis was conducted of each test item looking at such things as difficulty, discrimination index, and suitability of foils. The mean item difficulty for 4-response multiple-choice questions was 0.52, which is a bit low for multiple-choice questions with four responses each. To maximize item discrimination, desirable difficulty levels are slightly higher than the midpoint between random guessing (1.00 divided by the number of choices) and perfect scores (1.00) for the item. The ideal difficulty for the four-response multiple-choice questions used in this test should therefore be 0.63. The ideal difficulty

for the two-response true-false questions is 0.75.

Poor performing test items were reviewed and revised with the goal of improving each. Questions were rewritten for increased clarity and student understanding, and better alternative answers were prepared. A total of nine poor performing test items were revised. An additional five questions were added to the previous group of thirty to help improve the reliability of the test, and to enhance its validity in relation to the test’s framework. The pilot test was administered a second time during May 2006 to 354 of the same high school students who took the initial test. The mean score of these students was 20.8 out of 35 (59.6%), which is not unreasonable for a test designed to produce the maximum possible spread among scores. The high/low scores were 6/32. The standard deviation of the sample was 5.62, and the standard error of the mean 2.59. Three questions were still found to be unacceptable in their present form. The mean item difficulty of the remaining 32 valid questions was about 0.65 which approaches the ideal mean item difficulty for a test of this distribution of question types. A test with twenty-six 4-response items and nine 2-response items will ideally have an overall item difficulty of approximately 0.66.

The three low-performing items from the 35-item post-test were revised following a discussion with experts of what might have led to an unacceptably low discrimination index in each case. The problems associated with student understanding of the concepts or possible alternative interpretations of the question and responses were clearly identified, and the questions further refined. It is believed that this final revision will serve to increase the KR20 reliability above the revised 32-item pilot post-test value of 0.80.

The second revision of *NOSLiT*, now the final version, was administered to 36 in-service high school physics teachers with considerable teaching experience during two June 2006 workshops. The teachers, nearly all from the Chicago metropolitan area, had an overall mean score of 29.7 out of 35 or 84.8%. The fact that experienced high school teachers have a significantly higher mean score than high school students and a smaller standard error (see Table 1) is evidence of construct validity for the test. An item analysis of the 35 questions did not reveal any unacceptably low-performing test items. Test results do suggest, however, that even experienced science teachers retain some of the misunderstandings common to their students. Questions proving to be the most troublesome for these science teachers (difficulty index < 0.80) dealt with the definition of a scientific hypothesis, the definition of a scientific statement, the demand for empirical evidence, the development of likely explanations from evidence, the role of creativity in the scientific endeavor, the meaning of induction/deduction, the assumptions scientists make about nature, the importance of empirical evidence, the relationship between theories and laws, and the myth of the scientific method.

<b>Norming Groups:</b>	<b>N</b>	<b>Mean</b>	<b>Percent</b>	<b>Std Dev</b>	<b>Std Error</b>
High school science students	354	20.85	59.6%	5.62	2.59
High school physics teachers	36	29.69	84.8%	3.50	1.91

Table 1. Mean scores for various norming groups.

## Administering NOSLiT

NOSLiT is an un-timed test requiring about 30 minutes for nearly all high school students to complete as experiences with nearly 400 different high school students attests. NOSLiT probably is best used under pre-test, post-test conditions; it generally should not be used as an achievement test. Questions have been developed and selected to provide a maximal dispersion of scores. As can be seen from the pilot study samples, average scores on these tests hover in the vicinity of 50% to 60% for high school students. Unless the content of the test framework (Wenning, 2006) is directly taught, the results from any testing will probably be unacceptably low. NOSLiT is best used primarily for the purposes for which it was created: as a research instrument for identifying weaknesses in student understanding, improving instructional practice, and determining program effectiveness. Only in the case where the nature of science is directly taught using the NOSLiT framework should NOSLiT be considered a suitable instrument for holding teachers and/or students accountable for achieving specific goals.

NOSLiT can be used readily for educational research or during professional development workshops for both elementary- and secondary-level teachers to show learning gains among participants. As one reviewer of NOSLiT noted, "It sure would be hard for most elementary teachers." That might well be true. But, given the fact that NOSLiT is geared toward assessing expected knowledge and understandings of secondary-level students, elementary school teachers who are high school graduates, indeed college graduates, should be expected to understand the nature of science at the level of NOSLiT.

The author encourages widespread use of NOSLiT, and urges that test results be forwarded to him along with participant demographics so that the test can be normed using a variety of study groups. Users are requested to keep the instrument secure as with other standardized tests, and collect copies from students following testing. The names *Nature of Science Literacy Test* and NOSLiT should also be avoided with students to help prevent them searching the Internet for background information. Teachers, teacher educators, and science education researchers wishing to obtain a copy of the *Nature of Science Literacy Test* may download it as a password-protected portable document file (PDF) from the *Journal of Physics Teacher Education Online* Web site at the following URL: <http://www.phy.ilstu.edu/jpteo/NOSLiT.pdf>. The password may be obtained directly from the author of this article by e-mailing him at [wenning@phy.ilstu.edu](mailto:wenning@phy.ilstu.edu).

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