ANDREW CARL KEMP
Science Educators' Competing Views On the Goal of Scientific Literacy
(Under the direction of THOMAS R. KOBALLA, JR.)

This interpretive research study compares nine university science educators' views on the goal of scientific literacy, the aim that currently predominates much of science education in the United States. Personal interview data are analyzed using the constant comparative method of grounded theory research. A matrix-style model is derived to classify the participants' views on scientific literacy. Along one axis of the model lies the Conceptual, Procedural, and Affective elements or attributes that participants believe are necessary in scientifically literate people. Along another axis lies the rationales or purposes that participants espouse for the goal, which vary according the scale to which they are to be applied, and the extent to which they apply to practical uses for scientific literacy. I show that by simultaneously examining the rationales and elements, the participants' views can be classified into three separate groups, which I call the 'Practical,' 'Personal,' and 'Formal' views of scientific literacy. The main conclusion of the study is that these three views on scientific literacy have implications for competing policies, programs, and practices in science education. If this diversity of views on scientific literacy exists more widely among science educators, then it is potentially hindering efforts to improve the teaching and learning of science in the United States.

INDEX WORDS: Scientific literacy, Science literacy, Literacy in science, Science education, History of science education, Science educators, Public understanding of science, Interpretive research in science education, Rationales for science education.

SCIENCE EDUCATORS' COMPETING VIEWS ON THE GOAL OF SCIENTIFIC LITERACY

by

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DEDICATION

For my Father and Mother, who always told me I could do anything I wanted to as long as I put my mind to it and worked hard …

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INTRODUCTION

Scientific literacy is “the fundamental goal of science education” at the pre-college level in the United States (Bybee, 1997, p. 46). The *National Science Education Standards* (National Research Council, 1996) opens with the statement that “scientific literacy has become a necessity for everyone” (p. 1), and accordingly the explicit purpose of the *Standards* is to help “establish high levels of scientific literacy in the United States” (NRC, 1996, p. 21). The majority (83 %) of the 1000 adults polled in one recent survey of public opinion believe, “it is likely that most entry-level jobs in the next decade will require a basic level of science literacy” (The Bayer Facts Of Science VI, n.d.). A 1999 survey of more than 1700 members of the National Science Teachers Association (NSTA) found that 100 percent of the respondents feel it is “important” for adults to be science literate, and 68% said it is “essential” (The Bayer Facts Of Science V, n.d.). The National Association for Research in Science Teaching (NARST) declares in its Mission Statement “the ultimate goal of NARST is to help <u>all</u> learners achieve science literacy” (NARST 2000). Thus, policy-makers, researchers, teachers, and the general public seem to agree that the goal of scientific literacy is an appropriate focus for science education in the United States, especially at the K-12 level.

What is scientific literacy? Given that the term “scientific literacy” was coined 50 years ago (Conant, 1952) and is the focus of so much current attention, one might think this to be a relatively easy question to answer. However, the answer may very much depend on who you ask. Some critics claim the term “scientific literacy” has had multiple meanings since its origin, and that its meaning is still not clear. As Brickhouse, *et al*. (1989) put it, even though “Everyone seems to agree that Americans should be scientifically literate and that the promotion of public understanding of science is a ‘good thing' … "Definitions of scientific literacy are ubiquitous and elusive"(p. 157). Morris Shamos (1995) claims:

> there is no consensus on what 'scientific literacy' means or should mean. Instead, everyone involved with science education appears to have a vague, ill-defined notion of what it should mean, ranging from the simplistic view that any exposure to science contributes something to the state of mind called 'scientific literacy,' to the equally naive view that scientific literacy means being able to think like a scientist. (Shamos, 1995, p. 160)

Many others have also commented that scientific literacy lacks a clear definition or has too many of them to be useful (Agin, 1974; Champagne and Lovitts, 1989; Hurd, 1969; Mitman, et al., 1987; Roberts, 1983). Bybee (1997) says it is not that the term lacks a definition so much as "a clear definition of scientific literacy has not been generally *accepted*" (p. 86). Thus, in spite of the hundreds of publications concerning scientific literacy, Laugksch (2000) concludes that at the beginning of the 21st century there is still "a view that scientific literacy is an ill-defined and diffuse concept" (p. 71).

Need for the Study

Many terms in education can be charged with the defects of being 'ambiguous' and 'vague' (Brezinka, 1993). Even the term 'education' means different things to different people and in different contexts. In this, then, 'scientific literacy' is not exceptional. What is debatable, however, is "whether one should accept this state of affairs or attempt to overcome it" (Brezinka, 1993, p. 15). I take the position that a wide variety of views on the meaning of 'scientific literacy' can inhibit communication related to the concept, and can have practical implications as well (Champagne and Lovitts, 1989; Kyle, 1995a; Li, 1999; Maienschein, 1999). For example, development of the Third International Mathematics and Science Study (TIMSS) was temporarily held up in the early 1990s because the test-makers could not agree on "a precise, defensible definition of mathematics and science literacy" (Orpwood and Garden, 1998, p. 17). 'Reform' is the current watchword of science education, but until “the different conceptions of scientific literacy can be clarified and appropriately modeled, schools are unlikely to change traditional practice” (Raizen, 1991, p. 36). A consensus on the definition(s) of scientific literacy is necessary to give direction to science education curriculum development, research, and instructional practices. Conversely, lack of consensus on the meaning(s) of scientific literacy leaves the goal open to interpretation with the result that teachers do not know what to teach and the public does not know what to expect (Atkin and Helms, 1993). Atkin and Helms (1993) even declare that without a clear idea of what “scientific literacy for all” means the credibility of the entire science education profession might soon be brought into question.

The reader will note that scientific literacy might have more than one valid definition. Like many other terms, ‘scientific literacy’ could have different meanings depending on the contexts and purposes one has in mind (Walsh, 1993). Having multiple definitions only becomes a real problem when the meanings imply competition, i.e., to employ one sense commits the user to eschew other senses of the term. Given that time and resources available for pre-college science education are limited, different views of scientific literacy could lead to significant competition between programs and practices in science education (Atkin and Helms, 1993). Therefore, there is a need to examine the range and degree of compatibility of extant views on scientific literacy so that progress towards the goal can be facilitated.

Purpose of the Study

Educational goals or constructs, such as scientific literacy, often “take on a life of their own … before we know, literally, what we are talking about” (Wilson, 1986, p. 27). Wilson (1986) suggests that before educators uncritically accept (or reject) any given educational goal, they should attempt to answer at least three sorts of questions. First, there is the question of meaning, i.e., what is meant by the construct or goal state? What are its limits, properties, etc.? Second, what are the purposes that the construct/goal might serve? Who wants or needs to acquire this construct or educational state and why is it necessary or desirable? And finally, there is the question of methods or implementation. How can the construct/goal be promoted or improved in the (school) population? Unfortunately, the first two of these questions, which have logical priority, are rarely addressed in a critical manner (Wilson, 1986). Regarding the goal of 'scientific literacy,' the purpose of this dissertation is to look at the first two sorts of questions, and to draw implications for the third sort. More specifically, I interviewed nine university science educators to explore the range of contemporary meanings and purposes they assign to the concept of scientific literacy. Using interpretive research methods (Gallagher, 1991a), I derive a matrix-style model to classify the participants' views on scientific literacy, and then I briefly examine the compatibility of their views in terms of policies, programs, and practices in K – 12 science education in the United States.

It is not my purpose to try to end the discussion and debate on what scientific literacy is or how it functions in society. Rather, I hope this dissertation serves as a reference point for examining alternative views on scientific literacy, and as a starting point for more research into the long-term efficacy of the goal.

Research Questions

This interpretive study addresses the general research question, "What is the range and degree of compatibility of science educators' views on the concept of scientific literacy?" I take it as given that there are multiple meanings assigned to the concept of 'scientific literacy' because this problem is well documented (Agin, 1974; Bybee, 1997; Champagne and Lovitts, 1989; Hurd, 1969; Mitman, et al., 1987; Roberts, 1983; Shamos, 1995). What I am interested in discovering is how extant views on the concept of scientific literacy differ, and whether or not the variety of views are really different in degree or in kind. Put differently, I wish to explore whether or not the science educators who participated in this study are working towards the same or different—and possibly competing—goals.

Wilson (1986) suggests that two crucial aspects of an educational goal are the meanings and purposes assigned to it. Therefore, I will first attend to the issue of 'meaning' by addressing the research sub-question, "How do the participating university science educators define and describe the concept of scientific literacy?" That is, I identify and compare what each participant views as the essential 'elements' of the concept, as well what constructs they exclude from the province of scientific literacy. Next, I concentrate on a second research sub-question, "What rationales do the participants ascribe to the goal of scientific literacy?" That is, I explore the participants' views on the necessity or desirability of scientific literacy as an educational goal. Subsequently, I develop a framework to classify the participants' views by linking the rationales they espouse to the elements of scientific literacy they emphasize. Finally, I will briefly examine the compatibility and some general implications of the participants' views in terms of policies, programs, research, and practices in science education.

Definition of Terms

I cannot define 'scientific literacy' at this point because the controversy over its definition is at the heart of this dissertation. However, the reader should note that I do not make any distinction between the term 'scientific literacy' and the term 'science literacy.' Maienschein (1999) suggests that 'scientific literacy' refers to the scientific habits of mind needed by everyone, whereas 'science literacy' refers to the scientific knowledge particular to experts; however, that article is the only source I have identified that advocates such a distinction. Similarly, I find no substantial distinctions in the literature between the term 'scientific literacy' and the phrases 'literate in science' or 'literacy in science.' Evans (1970b) declared that "Literacy in science should not be considered synonymous with scientific literacy" (p. 81), but then went on to say that "literacy in science" is a "component of scientific literacy" (p. 81), so I will not distinguish between these terms either for the purposes of this dissertation.

The term 'scientific illiteracy' is sometimes used. Generally, as one might suspect, it is intended to mean "not scientifically literate." Bybee (1997) says a person who is scientifically and technologically illiterate cannot understand questions about science, or even locate them "within the domain of science or technology" (p. 82). However, he also says that everyone who has been to school can be considered scientifically literate to some extent, so only individuals with developmental disabilities (or perhaps very young children) might be classified as truly scientifically illiterate. Therefore, one should use the 'scientific illiteracy' term with caution, if at all.

Delimitations and Limitations

The scope of this study was intentionally delimited in certain ways. Other limitations of the study arise from external constraints and the nature of methods employed. Some of the study's delimitations and limitations are summarized below, and they are more fully discussed in Chapter 3.

Delimitations

There are a number of other stakeholders that one might investigate concerning the goal of scientific literacy, e.g., students, parents, teachers, university science educators, legislators, business people, and so forth. I chose to examine the views of only one of these groups, namely, university science educators, for several reasons. First, there is a "practical" consideration, i.e., the need to keep the study in manageable proportions. Second, I desired to conduct the study in depth rather than breadth, because I believed a broad study might result in a superficial examination of the problem. I also chose to study members of the science education community, and especially scientific literacy "experts," because I hoped they would reveal the greatest amount of relevant information of any of the potential stakeholders. University science educators are also my main audience for the final products of this study.

I further delimited my focus to scientific literacy in the United States. I think comparing United States educators' views on scientific literacy with educators from other countries might be interesting (e.g., Tippins, et al, 2000), but it is simply beyond the scope of what I considered possible for my dissertation study.

<u>Limitations</u>

Access to participants was a limitation of this study; potential participants are located throughout the country. I did have a small pool of funds for traveling, but there was no practical way to access everyone who might be considered (or who might consider themselves) scientific literacy experts. I interviewed the majority of participants while they were attending professional conferences.

Most of my data come from one-shot personal interviews. Although I attempted to follow up with written interviews, my participants did not always respond to my attempts. I also hoped to relate participants' interview data with their published views; however, some of the participants did not wish to have their identities revealed, so I chose to keep all the participants' identities in confidence and I was not able to triangulate my findings to the degree I had hoped. These facts combined with the small number of participants and the general ("subjective") nature of qualitative studies means that any results or hypotheses derived herein should be viewed as tentative, and should not be construed as fully representative of the science education community as a whole.

Summary and Preview

I have set forth here the premise that a major focus of pre-college science education in the United States is in need of critical examination. This goal, called 'scientific literacy,' may actually have a number of competing interpretations and supporting rationales that are hindering its pursuit. My research question is "What is the range and degree of compatibility of science educators' views on the concept of scientific literacy?" This general question is to be addressed by exploring the answers to 2 sub-questions: (1) "How do the participating university science educators define and describe the concept of scientific literacy?"; and (2) "What rationales do the participants ascribe to the goal of scientific literacy?" My goal is to develop a framework to classify the participants' views by linking the rationales they espouse to the elements of scientific literacy they emphasize. I hope the models developed herein to represent science educators' views on scientific literacy will assist researchers and practitioners in re-thinking the goal of scientific literacy and how it can be best pursued. Or alternatively, perhaps the models and other discussion will convince educators to abandon the goal in favor of another. In either case, my overarching aim is to help clarify the purposes of science education in the United States so that both research and practice can be more fruitfully applied.

In Chapter 2, I will discuss some of the conceptual perspectives and theoretical frameworks that have informed this study, including the history of science education reform and the scientific literacy goal from a national perspective. I will also examine recent criticisms of the goal of scientific literacy, especially those of Morris Shamos (1995).

In Chapter 3, I detail the methods I have used, including the theoretical framework for my methodology, and I discuss some of my own perspectives and assumptions that have no doubt influenced both the acquisition and interpretation of data in this study. I also discuss some delimitations and limitations of the study. The design of this study is situated in the interpretive research tradition in science education (Gallagher, 1991). I employed the constant comparative method of data analysis (Strauss and Corbin, 1990) to transcripts of interviews of 9 science educators, as well as selected publications pertaining to the concept of scientific literacy. Thus, transcripts and literature documents were analyzed in a series of coding cycles with the aim of inductively deriving themes, hypotheses, and models about the goal of scientific literacy (Strauss and Corbin, 1990).

Chapters 4 and 5 represent the findings of the study as well as discussion of those findings. Chapter 4 examines the elements of the 'scientific literacy' concept, and discusses one way to classify participants' views on the elements. Chapter 5 addresses the question of rationales attributed to the goal of scientific literacy. I also derive a Framework to Classify Views On Scientific Literacy that encompasses both the elements and rationales espoused by my participants. The final chapter presents a synthesis Narrative Model of Views on Scientific Literacy, and also deals with the compatibility and implications of various views for educational policies, programs, and practices in science education. I end with a series of recommendations for science education in the pursuit of the goal of scientific literacy in the United States.

CHAPTER 2

REVIEW OF THE RELATED LITERATURE

To set the study in context, this chapter gives a review of the literature informing the focus of this study. I first examine the history of science education and the scientific literacy goal in the latter half of the 20^{th} century. This review is followed by an examination of some of the criticisms of the concept and goal, especially the views of Morris Shamos who has written an entire book dedicated to debunking "The Myth of Scientific Literacy" (Shamos, 1995).

Short History of Science Education Reform and Scientific Literacy Goal

The goal of scientific literacy is intimately bound up in the history of science education, so an exploration of their shared history is an appropriate way to set the context for this dissertation. Additionally, quotes from sources later in the dissertation may refer to historical events, so an overview of the history of science education and the goal of scientific literacy may help the reader interpret the quotations. However, a complete overview of the history of science education and of scientific literacy would be both too ambitious and impertinent for present purposes. Since the term "scientific literacy" was apparently first used in 1952 (Conant, 1952), I will limit discussion of the history of science education to the post-World War II years. As the goal of scientific literacy has been largely left up to public grade schools (K-12), I will further limit my discussion to the pre-collegiate realm. Finally, in the interests of brevity, I will also limit my discussion to pertinent science education projects and trends with a national scope, as opposed to those at a local, regional or state level.

I examine the literature in more or less historical order. To facilitate the discussion, I follow a framework for sub-dividing scientific literacy's history established by Roberts (1983), although I slightly change some of the dates he used. The literature reviewed during the first period (1952-1962), the “period of legitimation,” includes almost all references made to scientific literacy that I can find in the science education literature (though I do leave out a couple found in the popular media literature). Thereafter, the references become increasingly selective as more and more publications referring to the goal of scientific literacy appear.

1952-1962: “Period of Legitimation”

Many science educators at the time of WWII and immediately thereafter were especially interested in school science that students would find personally useful (DeBoer, 1991; Matthews, 1994). This “applied” or “practical” approach was in consonance with the precepts of the child-centered progressive education movement that pervaded all of education prior to the war (Cremins, 1964; Ravitch, 1983). The Progressives, according to Cremins (1964), believed in:

1. “Broadening the program and function of the school to include direct concern for health, vocation, and the quality of family and community life”;
2. “Applying in the classroom the pedagogical principles derived from new scientific research in psychology and the social sciences”;
3. “Tailoring instruction more and more to the different kinds and classes of children who were being brought within the purview of the school”; and
4. Promoting “the faith that everyone could share not only in the benefits of the new sciences but in the pursuit of the arts as well” (pp. viii-ix).

In the early 1950s, United States science education began undergoing a number of changes due to several factors. For one thing, the educational system in general was experiencing an expansion as a result of the post-war “baby boom,” resulting in more public and governmental attention directed towards the schools (Ravitch, 1983). The “Cold War” was a reality, and some scientists and educators questioned whether progressive curricula were preparing students well enough in mathematics and science to provide the United States with the number of scientists, engineers, or science teachers perceived necessary to stay competitive, in both economic and military realms, with the Soviets (DeBoer, 1991; Hurd, 1958; Matthews, 1994; Raizen, 1991; Rockefeller Brothers Fund, 1958). Critics (e.g., Bestor, 1953; Lynd, 1953; Woodring, 1953) claimed progressive curricula were unfocused, unchallenging, and anti-intellectual, and they urged a return to the teaching of the core knowledge of the basic subjects, such as English, history, mathematics, and science (Ravitch, 1983).

The roots of the scientific literacy goal extend back two centuries or more (Bybee, 1997; DeBoer, 1991; Hurd, 1987, 1990, 1998; Oliver, Jackson, Chun, and Kemp, 2001). However, the term ‘scientific literacy’ was apparently first introduced about 50 years ago by the President of Harvard University, James Bryant Conant. Conant wrote a Foreword for *General Education in Science* (Cohen and Watson, 1952) in which he discussed the need for individuals to be able to evaluate the advice of experts:

> Such a person might be called an expert on 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 (Cohen and Watson, 1952, p. xiii, emphasis added).

In Conant’s view, then, scientific literacy is a matter of education and experience, and it results in the ability to “communicate intelligently” about scientific and technical matters. He did not define or use the term again, however, so we are left to speculate about its meaning. Conant saw the “scientific world view as a hallmark achievement of Western civilization” (quoted in Holton, 1998/99, p. 184). However, he was very interested in making sure that every student acquire some knowledge and appreciation of history, art, literature, and philosophy in addition to science (Conant, 1945; 1947). One is tempted to conclude, then, that by "scientific literacy" Conant had in mind a very broad conception of knowledge about science and its place in civilization.

One of the most important factors affecting changes in science education in the 1950s was the involvement of the federal government in both collegiate and pre-collegiate education. Prior to this time, the involvement of the United States federal government in education was viewed, at best, with suspicion (Ravitch, 1983). However, that attitude swiftly changed when the United StatesS.R. became the first nation to launch a satellite, *Sputnik,* in 1957 (Hurd, 1958; Rockefeller Brothers Fund, 1958). Following this historic event, a number of government agencies and initiatives (e.g., the National Defense Education Act of 1958, a.k.a. Title III) began to support reforms in science education (Hale, 1960; KY Division of Educational Research, 1968). Perhaps the most influential federal agency in science education reform was the National Science Foundation (NSF).

The NSF was founded in 1950 (Public Law 507, 81st Congress). Although NSF's primary purpose was to support basic scientific research, another of its original responsibilities was "to develop and encourage the pursuit of a national policy for the promotion of … education in the sciences" (Wolfle, 1957, p. 335). One way NSF pursued this mission was to sponsor "summer institutes" designed to provide teachers with advanced knowledge in a specific discipline (Waterman, 1960; Wolfle, 1957). The institutes were usually held at a college or university and were led by scientists and professors. The NSF summer institutes "ranged from what might be called an educational 'Operation Bootstrap' designed to take the least well-prepared teachers and introduce them to a few basic scientific facts to what is close to a federally financed graduate program which converts superior science and mathematics teachers into superb ones" (Krieghbaum and Rawson, 1969, p. 5).

The first institute in 1953 aimed to update the content knowledge of college teachers. In 1954, the NSF also initiated a summer institute for high school teachers (Wolfle, 1957). In 1956, there were only 18 of these institutes for pre-college teachers (Wolfle, 1957). However, in 1965 just a few years after *Sputnik*, there were 449 institutes with about 21,000 participating teachers (Krieghbaum and Rawson, 1969). Between 1954 and 1965, NSF appropriated about $165 million for Summer Institutes for secondary mathematics and science teachers (Krieghbaum and Rawson, 1969). By the late 1960s fully one-half of all secondary science and mathematics teachers had participated in some form of institute activity at some time in their career (Raizen, 1991).

Another way NSF influenced science education reform was by sponsoring the development of new curricular materials (Raizen, 1991). The first of these curricular projects, MIT's Physical Sciences Study Committee (or PSSC) was initiated in 1956--a year before the launch of *Sputnik*. Similar projects followed in chemistry, biology, and mathematics within the next few years. By 1975, NSF had given funds to 28 large-scale science curriculum reform projects (Matthews, 1994). Most of the early projects followed the model of PSSC, which used a team of leading scientists, science teachers, and instructional media experts to develop curricular materials, including textbooks and lab activities (Raizen, 1991). This use of teams and the active participation of first-rate research scientists in those teams was a marked departure from the preparation of traditional textbooks (and their associated curricula) by one or two authors, who were typically high school teachers or college science educators (Carleton, 1960; Raizen, 1991).

The projects developed in the 1950s and 1960s are often referred to by their initials and are nicknamed "the alphabet courses," or "ABC courses" (Roberts, 1983). The developers of the alphabet course projects criticized the previous curricular materials as being out of date, lacking broad unifying themes, failing to adequately develop fundamental concepts, covering too many topics, failing to portray the inquiry-oriented nature of science, and having too many technological applications (DeBoer, 1991). In contrast, the new science materials were largely theoretical in orientation, focusing on broad, unifying concepts within disciplines and on the processes of inquiry (DeBoer, 1991; Hlebowitsh and Wraga, 1989; Matthews, 1994). The alphabet curricula generally focus on the structure of the disciplines (Bruner, 1960) and on allowing students to act like scientists themselves by engaging in hands-on, inquiry-oriented activities (Schwab, 1962). In comparison to the progressive courses of the 1950s, Trowbridge and Bybee (1990, p. 291) say the junior high and high school alphabet curricular materials tended to have:

- less emphasis on social and personal applications of science and technology
- more emphasis on abstractions, theory, and basic science—the structure of the scientific disciplines
- increased emphasis on discovery—the modes of inquiry used by scientists
- frequent use of quantitative techniques
- newer concepts in subject matter
- an upgrading of teacher competency in both subject matter and pedagogical skills
- well integrated and designed teaching aids to supplement the courses
- little emphasis on career awareness as a goal of science teaching
- a primary orientation toward college-bound students.

The ultimate goal of most of these new high school science and mathematics curricular materials was to develop the country's "scientific manpower" (Hlebowitsh and Wraga, 1989; Raizen, 1991; Roberts, 1983; Waterman, 1960). There were some exceptions to this rule, however. For example, the philosophy of Harvard's Project Physics course was that physics is for everyone, not just specialists (Trowbridge and Bybee, 1990).

In the early aftermath of *Sputnik*, then, the goal of public scientific literacy received relatively little attention. A panel report for the "America at Mid-Century Series" project, commissioned by the Rockefeller Brothers Fund (RFD, 1958), included a short section about the "crisis" in United States science education that the writers attributed to "our breath-taking movement into a new technological era" (RFD, 1958, p. 28). The writers noted the technological prowess of the Soviet Union did not 'cause' the crisis, but rather served as a "rude stimulus to awaken us to that reality" (RFD, 1958, p. 28). They called for better education of scientists, but cautioned:

> There is a danger of training scientists so narrowly in their specialties that they are unprepared to shoulder the moral and civic responsibilities which the modern world thrusts upon them. But just as we must insist that every scientist be broadly educated, so we must see to it that every educated person be *literate in science*. In the short run this may contribute to our survival. In the long run it is essential to our integrity as a society. (RFD, 1958, p. 28, emphasis added)

However, this is the only use of the scientific literacy concept in the report.

In 1958, Paul DeHart Hurd published "Science Literacy: Its Meaning for American Schools" in the October issue of *Educational Leadership*. Even though he did not invent the term, Hurd's (1958) use of the term "scientific literacy" in this article is often given credit for introducing the concept as a major theme for science education (Bybee, 1997, Hurd, 1998; Laugksch, 2000; see Roberts, 1983, for a contrasting point of view). It is perhaps important to note that Hurd is an adherent of progressivism (according to several of the people I interviewed), and continued to be a strong advocate for the goal of scientific literacy for the next 4 decades.

Hurd (1958) observed "science with its applications in technology has become the most characteristic feature of modern society" (p. 13). He therefore (1958) contends:

> More than a casual acquaintance with scientific forces and phenomena is essential for effective citizenship today. Science instruction can no longer be regarded as an intellectual luxury for the select few. If education is regarded as sharing of the experiences of the culture, then science must have a significant place in the modern curriculum from the first through the twelfth grade. (p. 13)

However, Hurd never explicitly defines what he means by the term "scientific literacy" in his 1958 paper.

Hurd (1958) remarked that science education was being commented "upon by the President and debated in Congress" in the late 1950s. Opinions and money were also being contributed by businesses and industry. One such business was the Shell Chemical Corporation. Its president, Richard C. McCurdy, spoke about scientific literacy in a ceremony at Cornell University honoring the Shell Merit Fellowship recipients. His speech was published in the November issue of *The Science Teacher* with the title, "Toward a Population Literate in Science." McCurdy said an understanding and appreciation of natural science would "help prepare the student to participate in human and civic affairs, whatever his calling may be" (1958, p. 366). McCurdy advocated that all students be taught science, especially at the secondary level. He quoted from the "Rockefeller Report" referenced above, and also from the physicist Frederick Seitz (1958). In discussing the "non-science" student, Seitz (1958, p. 15) said he would

> Place primary emphasis on a continuing course in general science at the secondary school level, which gives familiarity with the history and accomplishments of science and its relation to the matters of everyday life. This should be descriptive and inspirational, placing emphasis upon the cultural roots and the goals of science and the countless ways in which it affects our understanding of the world about us.

Seitz, however, did not actually use the term "scientific literacy," and the above quotes are as close as McCurdy comes to defining what he means by "literate in science."

Margaret Mead, the famous anthropologist, used the term 'scientific literacy' in a 1959 paper:

> At present there is a growing effort to identify those children who display a particular type of intellectual ability and to provide a special education for them. … But this effort ought to be complemented by an effort to teach as fully as possible the advances in any field to other young children, and to adolescents

> and educated adults as well, so that we may have scientifically literate citizens and parents. (p. 143).

Even though Mead (1959) did not clarify what she meant by the term "scientifically literate," her paper is important to note here because it clearly shows awareness of scientific literacy as a separate goal from the preparation of scientific talent. Furthermore, she implies that the goal of scientific literacy is not just a matter for the public school teachers but also requires alternative or informal methods of pursuit. Similarly, Hubert Evans (1962) wrote that to pursue the goal of scientific literacy, schools and colleges need assistance "from other educational resources, including the mass media and the relatively small group of individuals who have specialized in popularizing science for the layman" (Evans, 1962, p. 75). Evans makes this comment in the context of a review of Issac Asimov's book, *The Intelligent Man's Guide to Science* (New York: Basic books, 1960). (Asimov was a prolific writer of both fiction and non-fiction books.) Evans does not define what he means by 'scientific literacy,' but he does say, "To be able merely to keep up with major advances in science and technology and to gain some understanding of what has been achieved also requires prolonged exposure to substantative content, including not only dependable knowledge but also the methods and procedures by which knowledge is obtained and certified" (p. 74). It is not clear if Evans means that a person must actually learn how to do science, or just know how science is done. In fact, perhaps surprisingly, none of the early writers about scientific literacy make it explicit that someone must know how to do science in order to be scientifically literate.

In November of 1959, the physicist, Polykarp Kusch, gave a speech to the 10th Thomas Alva Edison Foundation Institute entitled, "Education for Scientific Literacy in Physics." The speech was subsequently published in *School and Society* (Kusch, 1960). In it, he states, "every man with a serious pretension to having been educated should have made the attempt to acquire an understanding of science. The attempt, honestly undertaken, almost certainly will lead to scientific literacy if not to profound knowledge" (Kusch, 1960, p. 199). However, Kusch does not define what he means by 'scientific literacy.'

One of the most significant science education documents published during this period is *Rethinking Science Education: The Fifty-ninth Yearbook of the National Society for the Study of Education; Part I* (Henry, 1960). Although "its authors do … express sentiments analogous to those underlying the concept of scientific literacy" (Roberts, 1983, p. 31), only one uses a term related to 'scientific literacy.' The only exception is a lament by the executive secretary of NSTA, Robert Carleton (1960): "Although a large proportion of the citizens in our society have been exposed to science in the schools, the scientific illiteracy of the public mind is appalling. The products of science-teaching, as represented by the average citizen, are indeed disappointing" (p. 153). Carleton did not further discuss what he meant by "scientific illiteracy" and he does not use this or related terms again. This lack of discussion of scientific literacy is notable because both Paul Hurd and Morris Shamos were contributing writers to the 59th *Yearbook*. It is also notable because this is the first time that the term 'scientific illiteracy' was used, and it was employed—just as it seems to have been used ever since—as a cry for more (financial) support of science education.

While the notion of scientific literacy existed in the late 1950s, it was not a well-defined concept and was not a focus of the major reforms taking place in science education at that time. By 1960, "course content improvement" projects were well underway, and the NSF had already distributed "an estimated $175 million for the support and administration of programs directly related to the improvement of education in the sciences" (Waterman, 1960, p. 1347). However, NSF had only just started programs for the "public understanding of science," and had "supported a limited number of conferences and institutes in which scientists and science writers [were] brought together for the purpose of discussing the problems of communicating science to the layman" (Waterman, 1960, p. 1349). To underscore how little emphasis was being focused on general scientific literacy at this time, consider that Waterman (1960) uses the term 'scientific literacy' only once in his report on NSF's first 10 years: "The increasing significance of science and technology in relation to public policy, both national and international, has made it urgent that the level of scientific literacy on the part of the general public be markedly raised" (Waterman, 1960, p. 1349). Waterman (1960) did not offer any further description of 'scientific literacy.' Instead, he unambiguously states the primary objective of science education programs funded NSF in the 1950s was "to insure an adequate supply of competent scientists and engineers" (Waterman, 1960, p. 1347).

1962-1966: "Period of Serious Interpretation"

There seems to be little doubt that the "science pipeline" goal (Bailey, 1990) was a dominant purpose of science education in the early 1960s (DeBoer, 1991; Matthews, 1994). However, the goal of scientific literacy was also beginning to be seen as a legitimate pursuit. One major problem with the concept of scientific literacy, however, is that it had yet to be defined or even described in any detail. Up to this point, the term "scientific literacy" or related phrases were used as educational slogans (Scheffler, 1960); however, several attempts to clarify and define the concept appeared in what Roberts (1983) calls a "period of more serious interpretation" (p. 26).

The earliest reference I have discovered that attempts to define the concept of scientific literacy is an article by NSTA's first President (1944-1946), Philip G. Johnson (1962). Johnson's article, "The Goals of Science Education," appears in a special issue of *Theory Into Practice* devoted to science education. Johnson (1962) declares, "Most leaders in science education today agree that the overarching goal is the development of a scientifically literate citizenry" (p. 239). He then asks, "What is Scientific Literacy?" and devotes several paragraphs to an answer:

> The concept of scientific literacy must be based, first of all, on knowledge—a kind of knowledge that is much broader than mastery of detailed information. It

> suggests also the qualities of curiosity, accuracy of observation and interpretation, and open-mindedness.
>
> The person who is scientifically literate will be curious about the how and why of materials and events. He will be genuinely interested in hearing and reading about those things that claim the time and attention of scientists, and his interest will not be lessened by unwelcome ideas and events. He may never create any ideas pertaining to science, but he will be conversant with the ideas that are being considered in the intellectual marketplaces of the world.
>
> Perhaps one of the most important evidences of scientific literacy is the desire to determine the true quality of an idea—to be open-minded about one's own ideas and those of others. A scientifically literate person will try to be as accurate as possible in his observations and descriptions. His first expression of an idea, whether given that name or not, will be his hypothesis. When his further studies and the critical observations of others confirm earlier ideas, he will be ready to adjust his thinking in terms of the new information. Most important, too, he will require painstainking accuracy in others, and he will insist on being given the basis for making a judgment about the quality of ideas. This attitude will carry over into all areas—philosophy, foreign affairs, etc.
>
> Scientific literacy is, to a large extent, a matter of feelings and values, but these must be founded on knowledge, which, in most cases, starts in the classroom. Thus, the goals for science instruction in the elementary and secondary schools are most important. For example, we must consider the kinds of knowledge that should be presented and the specific attitudes and skills that should be instilled in students. (Johnson, 1962, pp. 239-240).

Johnson (1962) makes no reference to any source that had previously defined 'scientific literacy,' so his definition is in this sense 'stipulative.' But more importantly, Johnson's use of 'scientific literacy' is programmatic, i.e., it raises moral and practical issues and is "intended to embody programs of action" (Scheffler, 1960, p. 22). Johnson's (1962) intention was to point out that the reforms taking place in the early 1960s were aimed more at the able science student rather than the general student. Johnson (1962) attributed this "college preparatory" emphasis to the participation of scientists in the development of the new curricular materials. He concludes:

> Although scientists should willingly serve in these curriculum-development endeavors, they should be equally willing to accept a supporting role while science educators and leaders in curriculum development play the leading role. Only through such an approach is it likely that science programs will emerge that can be accepted and used by the great majority of teachers and school leaders. (p. 244)

After all, in Johnson's (1962) view, "the goals that recognize the needs of the general citizen must be prominent" (p. 244).

This difference in emphasis between conceptions of the goals of science education by scientists and science educators is also shown in the responses to a 'survey' conducted by Carleton (1963). Carleton asked 12 of "the nation's finest scientists and science educators" (1963, p. 33) to respond to three questions: (1) What does it mean to be scientifically literate? (2) How can you raise the level of your scientific literacy? (3) Why is it important that all teachers, along with other intelligent adults, be scientifically literate in today's world? Below I have selected some representative quotes from the scientists (all page numbers refer to Carleton's article).

- "There are two facets to scientific literacy: (1) some narrow-area contact—knowing and keeping up with at least one chosen, even though small, part of science, and (2) range contact—trying to keep in touch with a variety of other scientific developments" (Gerald Holton, professor of physics, Harvard University, p. 33).

- "Scientific literacy … does not require a survey and understanding of the whole of science and technology. A relatively small number of fundamental scientific concepts and conceptual schemes can be identified and, when understood, can form a firm foundation for understanding the nature of the sciences and scientific work and for interpreting the newer developments as they come along" (Hubert Evans, professor of natural sciences, Teachers College, p. 33).
- Scientific literacy "calls for familiarity with scientific methods and for sufficient knowledge in the several fields of science to understand reports of new discoveries and advances. … The teacher should [also] make a persistent effort to read current reports on scientific developments and engineering achievements in the press and in reputable magazines" (Howard A. Meyerhoff, chairman of the Department of Geology, University of Pennsylvania, and former executive director of NSF's Scientific Manpower Commission, p. 34).

While the remarks of the scientists (and science administrators) show they had somewhat different ideas of the nature of scientific literacy and how it can be achieved, it seems they all had essentially the same purpose in mind for learning about science, namely, to support the enterprise of science. Little attention is directed to other benefits of scientific literacy that might accrue to the individual or public. Despite giving more elaborate responses to Carleton's questions, the science educators display a similar quality of intent in their remarks. That is to say, they put a great deal of emphasis on becoming scientifically literate just so one may keep up with scientific developments and rally around science as a benefactor of human civilization. However, there is some hint that scientific literacy also helps individuals understand the world and their place in it. For example, John S. Richardson (Professor of education, Ohio State University) said: "The scientifically literate person has a knowledge of science adequate to an understanding of his environment. This knowledge helps him examine the world about him with respect to its rational explanations and to the processes by which the explanations have been derived" (p. 33). Similarly, Philip G. Johnson (professor of nature and science education at Cornell University) said, "Scientific literacy implies … that a person be able to read about, discuss, and write about natural materials, forces, and events in our surroundings" (p. 35).

Wittlin (1963) expressed the view that education towards scientific literacy should begin in the elementary school, if not before. Wittlin (1963) based this view on her observations of children, noting that their natural curiosity gives them "the makings for a candidate for scientific literacy" (p. 332). Wittlin (1963) describes the scientifically literate "layman" as having:

- A variety of information
- General and broad rather than deep knowledge
- Some understanding of inter-relations between fields of knowledge
- A realization of the contribution made by science to human welfare
- Appreciation of the bold intellectual adventure impled in scientific discovery. (p. 331)

In addition to these "capabilities," Wittlin (1963) says:

> To qualify for full-fledged scientific literacy the non-scientist may be reasonably expected not merely to be aware of [scientific] attitudes and to appreciate them, but in some measure to share them: curiosity and freedom of prejudice; imagination coupled with patient observation and disciplined reasoning; tentativeness of judgment and readiness to change it in the light of fresh evidence. (p. 331)

Interestingly, Wittlin (1963) says during adolescence:

> [E]ven these [students] who gain honors at science fairs and who may become scientists, will as a rule lose their previous encyclopædic [sic] interests. They

> will now seek more depth than breadth of knowledge. Only those who had a basis for scientific literacy laid in the elementary school years are likely to give some of their time and energy to reading or laboratory work outside a single narrow problem, or will return to the cultivation of their scientific literacy. (pp. 334-335)

Thus, Wittlin (1963) gives the impression that being a scientist or narrow-area specialist does not lead to scientific literacy, and may even work against it.

In an attempt to come up with a usable definition for 'scientific literacy,' Koelsche and Morgan (1964) took the "literacy" part of the term quite literally. Koelsche and Morgan published an "analysis of scientific information needed by persons living in the sixties to interpret and understand printed materials appearing in newspapers and magazines" (Koelsche and Morgan, 1964, p. 4). They analyzed the content of 22 daily newspapers and compiled a list of 175 principles and 693 vocabulary words that appeared during the 6-month study. Reflecting on their study, they derived the following "adequate" definition for scientific literary: "scientific literacy is a level of science education achieved by people when their backgrounds in science are such that they can understand, interpret, and interrelate scientific phenomena with facility, and form relevant and independent conclusions from information acquired through the media of mass communication" (Koelsche and Morgan, 1964, pp. 33-34).

At the same time that the goal of scientific literacy was becoming more recognized, it also received its first (printed) criticisms. Physics professor Morris Shamos (1963; see also Shamos, 1962) asked "Is it actually possible to develop a common literacy in science; and if so, what price must we pay for it?" (p. 42). Shamos (1963) devotes a lengthy section to "The Meaning of Scientific Literacy," which I reproduce in part here:

> What do we mean when we speak of a common literacy in science? We obviously do not mean competence in science to the extent of solving problems independently; this is the task of the specialist. Nor do we mean an

> encyclopedic knowledge of scientific facts. We mean, as Wilbur Schramm put it '… that an educated man should know science in a humanistic way.' He should know it for his general good and because it is part of his culture, just as he is expected to know history, philosophy, or literature. He should have a certain sophistication in science. He should feel comfortable when reading or talking with others about science on a non-technical level. Hopefully, he should be able to distinguish between scientific argument and dialectic.
>
> It is not necessary that he understand in detail the functioning of the telephone or the automobile, but that he know the difference between science and technology, and that he realize that Henry Ford and Alexander Bell, however great their achievements, should not be numbered among this nation's most distinguished scientists.
>
> Must he know *any* facts of science? Should he know, for example, that the Earth is round (or nearly so) and that it spins on an axi and rotates about the sun? … Of course he should—and more. He should know these facts of nature just as he knows various facts of history or literature or geography. They are a part of his environment, both real and intellectual. This sort of knowledge is natural history, not science as we shall understand it.
>
> More important, he should understand how these facts are determined and how they are used in the development of major conceptual schemes. In short, he should develop a feeling for the nature of the whole scientific enterprise, for its strengths and its limitations, and for its influence on man's intellectual development. (p. 46)

Shamos (1963) goes on to say that "we are nowhere near this kind of sophisticated scientific society" (p. 46), nor shall we be in the foreseeable future. He describes in this presentation many of the same barriers to achieving public scientific literacy that he will bring up again and again in following years, such as: the average person's unwillingness to learn science due to its reliance on mathematics; the nature of science which contradicts common-sense understanding; and the lack of evidence for the practical necessity to learn science to better one's life or circumstances (e.g., Shamos 1983/84, 1988a, 1988b, 1995, 1995b, 1996). He concludes that scientific literacy will not be achieved by the majority of people unless science education can somehow be reorganized around the "'great ideas' in science," requiring science in elementary schools, and training elementary school teachers how to teach science properly. Ironically, in spite of all his misgivings, in answer to his original question about the price of scientific literacy Shamos (1963) says:

> The task is clearly enormous, and the price is high in human energy and in time that must be taken from the youngster's other activities. Whether a common literacy in science, as we have defined it, is worth the price is a question that our society must judge. It is my conviction that the cost is trivial when compared with the potential benefits. (p. 51)

Thus, Shamos (1963) seems to support the goal of scientific literacy although he recognizes that it will be difficult to achieve.

The goal of scientific literacy reached a significant milestone in 1964 when it became the focus of one of the NSF sponsored projects, the Science Curriculum Improvement Study (SCIS). The stated objective of the SCIS project was "the increase of scientific literacy in the school and adult populations" (Karplus, 1964, p. 293). Karplus (1964) defined 'scientific literacy' as a "functional understanding of science concepts" (p. 296); that is to say, "to be able to use information obtained by others, to benefit from the reading of textbooks and other references, the individual must have a conceptual structure and a means of communication that enable him to interpret the information as though he had obtained it himself" (p. 296). This appears to be the first time scientific literacy was used to guide program development and student evaluation on a large scale. What is interesting to note is that this project was aimed at the pre-high school level. The early

NSF projects had been aimed at the high school level, and had the general goal of producing more scientists and engineers. However, high school science was not compulsory in most states in the early 1960s, so at first the NSF-sponsored projects affected only a minority of students who voluntarily took science at the secondary level. In order to get more students to take the optional secondary science courses, NSF funded several projects aimed at the pre-secondary school population by the late 1960s, including the Elementary Science Study and Science: A Process Approach (DeBoer, 1991; Raizen, 1991). It seems possible that even though the stated goal of SCIS was to increase public scientific literacy, an underlying purpose was to get more students to take more science in high school and college.

1966-1974: Period of "Initial Consolidation"

Following the development of SCIS, the goal of scientific literacy began to take on more prominence. In addition to targeting new audiences, the later alphabet curricula projects usually relegated the purpose of recruiting scientists as subordinate to the concern of teaching science to *all* students as part of their general education in elementary and junior high schools (Raizen, 1991). The desire to expose all students to science in the 1960s, especially at the elementary and junior high levels, took place in the broader context of a shift in general educational priorities toward a concern with equitable opportunities for underserved populations (DeBoer, 1991; Hlebowitsh and Wraga, 1989; Raizen, 1991). Largely as a result of the civil rights movement, new federal programs were initiated for minorities, children from low socio-economic backgrounds, children with disabilities, and non-native English speaking students (Ravitch, 1983). Coupled with this genuine desire to help the "underprivileged," an apparent glut of scientists and engineers reduced the perceived need for more efforts to train and recruit them (DeBoer, 1991; Raizen, 1991).

Roberts (1983) observes, "As the interpretations of scientific literacy continued, and continued to be diverse, it seems in retrospect to have been inevitable that someone would attempt an initial consolidation" (p. 33). Milton Pella, George O'Hearn, and Calvin Gale (1966a, 1966b; see also Pella 1967) at the University of Wisconsin's Scientific Literacy Center were among the first to make this attempt. They examined one hundred published works (1946-1964) to determine what science educators meant by the term "scientific literacy" and related phrases, e.g., "science and general education," "science and the public domain," etc. (1966b, p. 44). They conclude "that the scientifically literate individual is characterized as one with an understanding of the (1) interrelationships of science and society, (2) ethics that control the scientist in his work, (3) nature of science, (4) basic concepts in science, (5) differences between science and society, and (6) interrelationships of science and the humanities" (Pella, et al., 1966b, p. 44). Furthermore, the first three of these referents appear with twice the frequency of the latter three, perhaps indicating "their level of importance to the scientific literacy of an individual" (Pella, et al., 1966b, p. 44).

The idea of scientific literacy was now so well established that some science educators thought the entire science curriculum could (and should) be developed to support the goal. Victor Showalter (1968) was among the first to build a model for an interdisciplinary (or unified) K-12 curriculum around the goal of scientific literacy. Interestingly, Showalter did not use any of the foregoing literature about scientific literacy to define the goal, but rather took the position that "efforts to delineate 'scientific literacy' have often been concurrent with identification of general objectives of science education" (p. 3). He therefore refers to (and slightly modifies) the six objectives for science curricula outlined by Richard Haney (1966) as his view of scientific literacy to use as a framework:

1. The pupil should acquire knowledge which he can use to predict, understand, and control natural phenomena.

2. The pupil should grow in his ability to engage in the processes of science and to apply these processes in appropriate situations as he confronts them in his daily life.
3. The pupil should acquire the attitudes of scientists and learn to apply these attitudes appropriately in his daily experiences.
4. The pupil should come to understand the various interrelationships among science, technology, and society and to perceive his personal involvement in these activities.
5. The pupil should learn and develop numerous psychomotor skills through the study of science.
6. The pupil should acquire a variety of interests in and enthusiasm for science.

Showalter acknowledged that, "Not all individuals will, can, or should achieve exactly the same level of scientific literacy. However, each individual should have a clear opportunity to develop further scientific literacy at all levels of his intellectual development (i.e. at all grade levels K-12)" (p. 2).

However, not all science educators thought scientific literacy was defined well enough to be used as a framework for science curricula. Haven Kolb (1969) summarized the uncertainty of the meaning of "scientific literacy" for the teaching-learning situation:

> To some it means merely dissemination through the school population of miscellaneous ephemeral facts. To others it means inculcation of a spirit of inquiry. To still others, it requires abundant student experience with laboratory investigation—inquiry in action and not merely dry-runs or passive witnessing of colorful screen-shadows; and it may include appreciation of the work of scientists. To many the social relevance of science, and of the technology springing from it, is the only really important aspect. True scientific literacy, however, must be some combination of these.

Kolb (1969) said "a fairly clear picture of the meaning for scientific literacy" (p. 21) is given by a statement Paul Hurd prepared for the National Science Teachers Association (NSTA) in 1968. This statement (taken from Kolb, 1969, and shown in Figure 2-1) is among the most complex articulations to date of the characteristics or attributes of a scientifically literate individual. Basically, Hurd says a scientifically literate person understands and appreciates science as a way of knowing, understands the nature of science, appreciates the interaction of science and technology, understands the natural world, is aware of the mutual influences of science and society/culture, and appreciates the objectivity of science. However, in spite of his own endeavors in this realm, Hurd (1969) later commented that while "No one seems to deny that developing a scientific literacy is an essential component of general education, … there is little agreement as to just what this means" (p. 108).

In an article for *The Science Teacher* early in 1970, Hurd combined the idea of 'scientific literacy' with the components of "a humane literacy" (p. 14) and called this new goal "scientific enlightenment." In addition to modernizing the curricula, Hurd (1970) was proposing that science education should be reoriented around "the broader perspectives of society" so that it would "be vital for the advancement of the individual rather than for the promotion of science" (p. 14). A particular concern that he was addressing is that the scientific enlightenment (or literacy) prevents and deters "antiscience feeling[s]" that he perceived among current students, including "the notion that science has spawned an unmanageable technology which seems to swamp human individuality" (p. 13). Toward this end, in his list of "knowledge and attitudes" possessed by the "scientifically enlightened person" Hurd (1970) includes:

- Understanding "the purposes of the scientific endeavor to be the establishment of general laws and the conceptualization of knowledge about the natural environment"
- Understanding "Scientists and technologists must interact with an enlightened citizenry to create a favorable environment for the survival of each"

- "Awareness of the need to generate a system of concepts within which science, society, and the humanities can fit" (pp. 14-15).

THE SCIENTIFICALLY LITERATE PERSON

A statement of goals for an education in the sciences should describe what we mean by a scientifically literate person living in modern times. This person is the end product, as we see him, of ten to fifteen years of science education, beginning with kindergarten. Here are some of the ways by which we can identify this person:

- He has faith in the logical processes of science and uses its modes of inquiry, but at the same time recognizes both their limitations and the situations for which they are peculiarly appropriate.
- He enjoys science for the intellectual stimulus it provides, for the beauty of its explanations, the pleasure that comes from knowing, and the excitement stemming from discovery.
- He has more than a common sense understanding of the natural world.
- He appreciates the interaction of science and technology, recognizing that each reflects as well as stimulates the course of social and economic development, but he is aware that science and technology do not progress at equal rates.
- He is in intellectual possession of some of the major concepts, laws, and theories of several sciences.
- He understands that science is one but not the only way of viewing natural phenomena and that even among the sciences there are rival points of view.
- He appreciates that knowledge is generated by people with a compelling desire to understand the natural world.
- He recognizes that knowledge in science grows, possibly without limit, and that the knowledge of one generation 'engulfs, upsets, and complements all knowledge of the natural world before.'
- He appreciates the essential lag between frontier research and the popular understanding of new achievements and the importance of narrowing the gap.
- He recognizes that the meaning of science depends as much on its inquiry process as on its conceptual patterns and theories.
- He understands the role of the scientific enterprise in society and appreciates the cultural conditions under which it thrives.
- He recognizes the universality of science; it has no national, cultural, or ethnic boundaries.

Figure 2-1. Hurd's (1968) statement for the NSTA (from Kolb 1969, pp. 21-22)

Other than these three attributes, and perhaps a more explicit emphasis on having a historical perspective, Hurd's list of characteristics of the scientifically enlightened person is very similar to his (NSTA) 1968 list of characteristics of the scientifically literate individual.

In an article for *The American Biology Teacher*, Thomas Evans (1970b) states that while scientific literacy "is generally accepted by science educators as a major goal of science teaching … little effort has been given to defining the term properly" (p. 82). Evans (1970b) says this problem is "the greatest obstacle to a scientifically literate citizenry. If its meaning is not clear, scientific literacy can only be attained by chance" (p. 82). Evans (1970b) gives a very elaborate description of scientific literacy, which is based, in part, on the work of Pella, *et al*. (1966b). His description also resembles Hurd's (1970; NSTA, 1968), although he does not cite Hurd as a source. Within his discussion, Evans (1970b) states, "there is a minimal list of basic concepts and conceptual schemes that any scientifically literate person must understand" (p. 81). However, he acknowledged that to date "there is little agreement as to what should be included" in this list (p. 81).

In the early 1970s, NSTA identified scientific literacy as the most important goal of science education. NSTA's Board of Directors approved a position statement on "School Science Education for the 70's" that began with the words: "The major goal of science education is to develop scientifically literate and personally concerned individuals with a high competence for rational thought and action" (NSTA, 1971, p. 47). The statement declares that the scientifically literate person:

- uses science concepts, process skills, and values in making everyday decisions as he interacts with other people and with his environment
- understands that the generation of scientific knowledge depends upon the inquiry process and upon conceptual theories
- distinguishes between scientific evidence and personal opinion

- identifies the relationship between facts and theory
- recognizes the limitations as well as the usefulness of science and technology in advancing human welfare
- understands the interrelationships between science, technology, and other facets of society, including social and economic development
- recognizes the human origin of science and understands that scientific knowledge is tentative, subject to change as evidence accumulates
- has sufficient knowledge and experience so that he can appreciate the scientific work being carried out by others
- has a richer and more exciting view of the world as a result of his science education
- has adopted values similar to those that underlie science so that he can use and enjoy science for its intellectual stimulation, its elegance of explanation, and its excitement of inquiry
- continues to inquire and increase his scientific knowledge throughout his life (pp. 47-48).

A difference between this list and NSTA's 1968 list of attributes is that the 1971 list does not include the objective of recognizing the "universality of science," i.e., the awareness that it "has no national, cultural, or ethnic boundaries" (NSTA, 1968; Figure 2-1). Perhaps the most interesting difference in the NSTA 1968 and NSTA 1971 lists of scientific literacy attributes is the inclusion in the latter of the characteristic, "continues to inquire and increase his scientific knowledge throughout his life." Even though Hurd, author of the NSTA 1968 statement, often spoke elsewhere about the need for citizens to be able to cope with rapid changes in science and society (Hurd 1958, 1960, 1969, 1970), he did not explicitly include the life-long learning attribute in his (NSTA) 1968 list. Nor did Hurd explicitly specify that the scientifically literate individual "has adopted values similar to those that underlie science" (NSTA 1971, p. 48), although he did say "He has faith in the logical processes of science" (see Kolb, 1969, p. 21).

The late 1960s and early 1970s was a time in which the public's consciousness was being raised in relation to environmental concerns. Accordingly, science educators began to call for ecology and/or environmental education to become part of the scientific literacy goal. O'Hearn (1972), for example, suggested that environmental education should be viewed as "the new scientific literacy" (p. 21).

In 1974, Norman Smith posed the question "What is meant by the term 'scientific literacy?'" (p. 34). He said the term was "frequently used but seldom defined " (p. 34), then went on to describe it as implying three abilities:

1. The "ability to *understand* the material that confronts us," i.e., "our everyday scientific and technological concepts, objects, and systems";
2. The "ability to *verify*" the accuracy of media reports;
3. The "ability to *evaluate* and to *apply*" materials (products), ideas, and principles, especially in relation to society and the natural environment.

Smith suggested one or more of these abilities should be used in every encounter we have with a scientific or technological idea" (p. 34). However, he acknowledged that acquiring these abilities is no easy task because "the infinite scope of science and our own limited qualifications make it unlikely that anyone—and even full-time scientists—can ever fully understand all the scientific and technological ideas that might cross his path" (p. 34). Therefore, he recommended that scientific literacy could "be more realistically defined as a *challenge* than as a *goal* to be sought" (p. 34).

Also in 1974, Michael Agin expressed concern that

> Many individuals use the term 'scientific literacy' but fail to give it an adequate meaning; they assume that everyone knows what the concept means. There is, therefore, a need for a more specific definition or description of the concept so that better communication is possible. A frame of reference should be established to help consolidate and summarize the many definitions. (p. 405).

Agin's (1974) main contribution to the development of the scientific literacy concept was to summarize the "dimensions" of each of Pella, *et al*.'s (1966a) referents. Presumably, the scientifically literate person knows, understands, can do, or appreciates each of these dimensions (Figure 2-2).

<u>1975-1982: "Period of Further Interpretation"</u>

The United States economy began to suffer from periodic bouts with inflation and recession during the late 1960s and early 1970s. At the same time, United States public school enrollment decreased leading to teacher surpluses. As a consequence, education budgets decreased, and "the willingness to try innovations, which characterized the educational expansion after World War II, gave way to the need for retrenchment" (Raizen, 1991, p. 22), thus another "back to the basics" movement ensued. In addition, the NSF's budget for pre-college education programs began to dry up after Congressional criticism of their costly and seemingly never-ending nature (DeBoer, 1991; Raizen, 1991). One of the curriculum improvement projects, in particular, created such turmoil that pre-college teacher programs received almost no funding from NSF in 1976 (Hlebowitsh and Wraga, 1989; Raizen, 1991). This project, *Man: A Course of Study*, was controversial for two (albeit related) reasons. First, the subject matter was controversial because it involved human adaptation to the natural environment, a subject not well received by certain vocal religious groups. And second, NSF not only paid to create the project, but also to publish and disseminate it, giving the impression the federal government was imposing its (controversial) values upon the schools (Raizen, 1991). *Man: A Course of Study* became the subject of several Congressional investigations and Executive branch panels, and the scrutiny soon brought all of NSF's education programs under fire, essentially bringing the development of the "alphabet curricula" projects to a standstill (Hlebowitsh and Wraga, 1989; Raizen, 1991).

Science and Society

- Science is a root of social change
- Society controls science though the control of resources.
- The intelligent direction of science in a free society depends upon an informed public.
- Science has done much to liberate man from the bondage of superstition and other false beliefs.
- Science and technology have created social problems never before faced by a society.
- Science and technology are key elements for future change.
- Science and technology have limitations.
- The lay public must come to understand the scientist and his methods.

Ethics of Science

- All facts and concepts of science undergo objective critical analysis—sometimes referred to as empiricism or objectivity.
- Science includes a constant search for new and superior explanations of phenomena-parsimony or reductionism.
- All theories, laws, etc., are based upon evidence rather than self-evident truths, tradition, or the power of special interests—open-mindedness, skepticism, and tentativeness.
- The aim of science is to increase knowledge of the physical and biological world without respect to any present or future good or evil—immunity.
- Secrecy in science cannot be tolerated; the scientist has the duty to report his findings to the general public in a manner that the layman understands—relevancy.

Nature of Science

- Science proceeds as a series of approximations; it attempts to achieve a systematic and comprehensive understanding of the probabilistic essence of nature.
- Science is not a finished enterprise, much is yet to be discovered, its theories are tentative, and the use of these theories is contingent upon their adequacy, rather than their correctness.
- Scientific knowledge is based upon observation of samples of matter that are accessible to public investigation and are capable of being replicated through independent and competent investigations.
- Science proceeds on the assumption, based upon experience, that time, space, and matter are real and that nature is not capricious but consistent.

Figure 2-2. Dimensions of the Referents for Scientific Literacy (Agin, 1974)

- Every effect has a cause that can and should be quantified; the formulation as well as establishment of laws are facilitated through the development of quantitative distinctions
- There is no method of science but many different possible ways of conducting scientific investigations.

Knowledge of the Concepts of Science

- All matter is composed of units called fundamental particles; under certain conditions these particles can be transformed into energy and vice-versa.
- Matter exists in the form of units which can be classified in hierarchies or organizational levels.
- The behavior of matter in the universe can be described on a statistical basis.
- Units of matter interact. The basis of all ordinary interactions are electromagnetic, gravitational, and nuclear forces.
- All interacting units of matter tend toward equilibrium states in which the energy content (enthalpy) is a minimum, and the energy distribution (entropy) is most random. In the process of attaining equilibrium, energy, matter, and energy-matter transformations occur. Nevertheless, the sum of energy and matter in the universe remains constant.
- One of the forms of energy is the motion of units of matter. Such motion is responsible for heat and temperature and of the states of matter: solid, liquid, and gaseous.
- All matter exists in time and space and, since interactions occur among its units, matter is subject to some degree to changes with time. Such changes may occur at various rates and in various patterns.

Science and Technology

- Science and technology tend to differ only in motivation and purpose
- Pure science often produces technologically useful knowledge, and technology often produces conceptual schemes useful to pure science.
- Technological aspects of society are the link between the scientist and the nonscientist.
- Science and technology are the chief internal sources of change in our society.
- Science and technology interact directly with society.
- Most important social, economic, and political problems are related to the advances of science and technology.

<u>Figure 2-2.</u> Dimensions of the Referents for Scientific Literacy (Agin, 1974) (continued)

Science and the Humanities

- 'Science is one of the humanities;' man should know science in a humanistic way.
- The separation of science and the humanities is based upon ignorant misconceptions.
- Society requires wisdom and consensus for policy decisions which in turn necessitates communication between scientists and humanists.
- Science is part of our cultural heritage.

Figure 2-2. Dimensions of the Referents for Scientific Literacy (Agin, 1974) (continued)

Appraisal of the NSF reforms. After hundreds of millions of dollars in federal government investment and two decades of effort, how successful were these reform projects? The general conclusion seems to be that the curricular reforms of 1956-1976 were at best only partially successful in improving students' success in school science or in retention of science knowledge and skills. Numerous studies were conducted on individual projects (e.g., Bowyer and Linn, 1978) and some studies reviewed their collective success more generally (e.g., Helgeson, *et al*., 1977; Stake and Easley, 1978; Weiss, 1978; and Harms and Yager, 1981). Perhaps the most remarkable aspect of the reform projects

> was the scale of the endeavor and the extent to which the projects were actually completed and used in the schools. The national scope of the projects, the funding by the federal government, the widespread use of the courses across the country, and the involvement of noted scientists in the creation of the courses all made this effort unmatched in the history of American education. (DeBoer, 1991, p. 166).

If judged in terms of dissemination, the impact of the federally supported curricular reforms "was impressive" (DeBoer, 1991, p. 167). By the mid-1970s, more than half of the nation's school districts were using at least one of the NSF or other federally funded science curricula for grades 7 - 12, and about 30% of the districts were using them in elementary schools (Jackson, 1983; Weiss, 1978). In addition, "a number of the ideas that were proposed by the curriculum project committees were in fact incorporated into commercially prepared textbooks during the period following their initial appearance" (DeBoer, 1991, p. 169), thus the projects had an indirect influence for many students and teachers who did not use the alphabet curricula themselves.

If judged in terms of enrollment and student learning, however, the reform projects of 1956-1976 were not overly successful. For example, one disappointing finding was that enrollments in the optional high school science classes, such as physics and chemistry, remained largely unchanged during the 1960s (DeBoer, 1991). Hurd's (1970) analysis of the government-funded programs lists 14 strengths and 13 weaknesses. Overall, he concluded that the new courses were too difficult and uninteresting for the typical student. DeBoer (1991) says:

> They did not take into account the importance of student interest or the pedagogical need to relate science knowledge not only to broad unifying themes of the discipline itself but also to the experiential world of the student, nor did they sufficiently consider the importance of readiness for learning and the need to postpone abstract learning until the student was capable of dealing successfully with such intellectual complexity. In addition, many of the projects ignored one of the most important reasons for teaching science in any culture at any time, namely, to provide individuals with the knowledge and skills that would help them live intelligent lives in the culture in which they found themselves. (pp. 171-172)

Or as Hlebowitsh and Wraga (1989) put it, "a retrospective glance reveals that the reforms were deficient in terms of meeting student needs and in unifying the curriculum" (p. 411).

Some science educators believe the ABC curricula had shortcomings related to the dominance of scientists, rather than science educators, in the development of the materials. Hlebowitsh and Wraga (1989), for example, say the scientist-specialists who wrote much of the material "had little understanding of the realitites of the educational situation" (p. 411). Duschl (1985) says that the curriculum writers failed to apply educational research to the creation of the materials, and also emphasized an out-dated conception of inquiry and the nature of science in the courses. Others think the curricula were good in and of themselves, but that problems arose in implementation (Matthews, 1994). That is, the problem was not with the course materials, but with the teachers and other parts of the system of schooling in the United States. For example, case studies of teachers found that although teachers now had new course materials, they continued to teach in the same old way (Stake and Easley, 1978). In addition, school systems did not have enough money to provide lab assistants, buy equipment, or support teachers' professional development that could have helped the new curricula to succeed (Matthews, 1994).

Perhaps the main lesson learned from this period of reform is that while curricular change is important, it is not enough: "the mere change of curriculum, without change of teacher education, assessment tasks, resources and support, is not going to have any dramatic effect on student engagement, interest and learning of science or of any other subject" (Matthews, 1994, p. 20). This lesson was taken to heart in the reforms of the 1980s and 1990s, when the emphasis became one of "systemic" reform.

<u>Scientific literacy advances.</u> Lacking public and financial support for reform and improvement, United States science education could be said to have entered a period of relative stasis from the mid-1970s to the early 1980s. However, several important developments in the concept of scientific literacy occurred. The first came in 1975 when Benjamin Shen suggested scientific literacy could be subdivided into three categories:

- *Practical science literacy*, which means "the possession of the kind of scientific knowledge that can be used to help solve practical problems," especially those related to health and survival (Shen, 1975, p. 46).
- *Civic science literacy*, with the aim of enabling "the citizen to become more aware of science and science-related issues so that he ... [can] participate more fully in the democratic processes of an increasingly technological society" (Shen, 1975, p. 48).
- *Cultural science literacy*, which is about knowing "something about science as a major human achievement" (Shen, 1975, p. 49).

Shen also gave an overall definition for "science literacy": "an acquaintance with science, technology, and medicine, popularized to various degrees, on the part of the general public and special sectors of the public through information in the mass media and education in an out of schools" (Shen, 1975, pp. 45 – 46). Shen's article was important because "he describes a social orientation and contextual emphasis for the various topics elaborated by other authors. Shen's view also encompasses a continuum of global, national, and personal dimensions" (Bybee, 1997, p. 58).

Michael Agin organized a symposium on scientific literacy at the 1975 annual meeting of NARST (Roberts, 1983). At least two of the papers presented at this symposium were subsequently published (O'Hearn, 1976; Pella, 1976; see also Klopfer, 1976). Pella (1976) asserts that the youth of many nations, including the United States, appeared "to be turning science off for a variety of reasons, one of which may be because science is still taught to produce big scientists and little scientists, rather than literate citizens" (p. 98). He subsequently lists 15 "guesses as to the needs of a literate citizen" (p. 99), which he felt could be helpful in reorienting science education. According to Pella (1976), a literate United States citizenry:

1. is able to communicate within itself and with other citizens of the world relative to knowledge or ideas of the nature of natural objects and phenomena.
2. is able to communicate within itself and with other citizens of the world relative to the utilization or control of natural objects and forces.
3. is able to utilize respected empirical concepts and laws in its constant adjustment to the environment
4. is able to explain events in its environment in a rational manner.
5. is able to predict events in its environment in a rational manner.
6. is able to read accounts of developments by the scientific community.
7. is aware of how empirical concepts and laws probably come into being.
8. is aware of the difference between theoretical concepts and laws and empirical concepts and laws
9. can use theoretical laws in unifying (explaining) empirical laws
10. is aware of how theoretical concepts and laws come into being.

11. is aware that the knowledge developed in the scientific community is probable rather than absolute
12. knows that theoretical and empirical laws are statements of postulated and/or observed relationships or uniformities, respectively, that are formulated utilizing vocabulary with conceptual meanings that may be descriptive, comparative, or quantitative; hence these laws may be descriptive, comparative, or quantitative.
13. is able to translate experience with the natural world into knowledge
14. is aware of the regulatory principles accepted in the scientific community that are employed in the generation and application of empirical and theoretical knowledge
15. is aware that science is concerned with the empirical universe

Pella (1976) summarizes his list like this: "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 library, knows where the contents of the library come from, and knows some of the regulatory principles involved in knowledge production and use" (p. 99).

O'Hearn (1976) does not offer a definition of scientific literacy, but instead relies on those published earlier (e.g., Pella, *et al*., 1966) to suggest "the future" could be used as an organizing principle for a science education that has scientific literacy as its goal.

In March 1977, Lawrence Gabel presented the results of his dissertation study at the 50th annual meeting of the National Association for Research in Science Teaching. Gabel (1976) said it is important to "develop a theoretical definition of scientific literacy" for at least four reasons:

1. To have a valid, comprehensive, and functional definition at the present time.
2. To facilitate communication in reference to the educational goal of developing scientifically literate citizens.

3. To provide a basis for developing science education programs which will enable students to attain appropriate levels of scientific literacy.
4. To provide a basis for developing an instrument to assess student achievement in the identified dimensions of scientific literacy. (p. 22).

Gabel (1976) compiled a number of statements about scientific literacy behaviors, most of them from definitions or descriptions of scientific literacy extant in the literature, and some that he generated himself. He arranged these statements into a Theoretical Model of Scientific Literacy (TMSL), and then "tested" his model (using a Q-sort technique) on 185 participants in the Columbus, Ohio area. Following a factor analysis of the data, Gabel (1976) developed and named 9 dimensions as the most important components of scientific literacy (for high school graduates) identified by his respondents. These dimensions include:

1. Scientific inquiry
2. Maintaining current awareness
3. Valuing methods of science
4. Personal application of science
5. Distinguishing between science and technology
6. Utilizing factual knowledge
7. Mutual involvement of science and society
8. Science as a human endeavor
9. Using natural resources

These nine dimensions could be considered Gabel's (1976) "inferred" definition of scientific literacy. The first three "TMSL behaviors" listed here were the most "highly valued" overall. Only the first seven behaviors are common to both scientists and non-scientists. "Science as a human endeavor" is a factor for the science group, but not the non-science group. The reverse is true for "Using natural resources." Since not all the initial dimensions of this theoretical model (the TMSL) received an emphasis from his participants, Gabel (1976) concluded many of the definitions of scientific literacy in the literature up to that time "had many types of statements which simply did not show up in the inferred dimensions of scientific literacy" in his study (p. 254). Therefore, "It would appear that many science educators have been operating from a perspective that is quite different from that of the 'layman's' perspective in terms of what is most important with regard to science for most high school graduates. The layman's perspective appears to be much more pragmatic than that of the science educator's" (Gabel, 1976, pp. 254-255). Thus, while there are a large number of extant definitions and descriptions of scientific literacy, not all of these conceptions are equally valid, especially when compared to the expectations of the public.

In 1976, NSF responded to Congressional pressure and awarded 3 contracts "to assemble information that would provide a picture of K-12 science education" (Harms and Yager, 1981, p. 2). One study by Helgeson and colleagues (1977) at Ohio State University summarized science education literature from 1955-1975. A second study headed by Iris Weiss (1978) of the Research Triangle Institute surveyed teachers and other school personnel about curricula, teaching, enrollments, etc. And the third study, conducted by Stake and Easley (1978) of the University of Illinois, investigated the science education practices at 11 schools through a case-study method. These studies, along with NAEP data, a scrutiny of science textbooks, and a literature review of the goals and objectives of science education were later analyzed and summarized by a team of 23 science educators led by Norris Harms of the University of Colorado. The efforts of this "Project Synthesis" were made public in *Volume 3: What Research Says to the Science Teacher* (Harms and Yager, 1981). Interestingly, the term 'scientific literacy' is not defined and actually is seldom used in the Project Synthesis report (Harms and Yager, 1981).

<u>The Science-Technology-Society approach.</u> Interview participants in this study sometimes refer to "STS," by which they mean "Science-Technology-and Society." STS

is a theme for or approach to science education that assumes learning science through technology and social issues offers a potential avenue to increased literacy and appreciation of *both* science and technology in our society (Bybee, 1987; Shamos, 1995). Throughout the 1970s and early 1980s, scientific literacy came to be closely associated with the science-technology-society theme (e.g., Gallagher, 1971; Hurd, 1975; NSTA 1982). In fact, in 1982 the NSTA Board adopted a position statement, entitled "Science-Technology-Society: Science Education for the 1980s" (see Figure 2-3; Brown and Butts, 1983), which asserts "There is a crisis in science education," and lists some of the STS problems that "demand immediate attention." The statement issues the following "Declaration":

> The goal of science education during the 1980s is to develop scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision making. The scientifically literate person has a substantial knowledge base of facts, concepts, conceptual networks, and process skills which enable the individual to continue to learn and think logically. This individual both appreciates the value of science and technology in society and understands their limitations. (Brown and Butts, p. 109)

The Declaration goes on to give a list of attributes that "help to describe a scientifically literate person" (p. 109), which I have reproduced in Figure 2-3. The position statement notes: "Each attribute should be thought of as describing a continuum along which the individual may progress" (Brown and Butts, 1983, pp. 109-110). The NSTA Board later approved a similar list of attributes in 1990 (see Yager, 1993; Figure 2-4).

The scientifically and technologically literate person:

- Uses science concepts, process skills, and values in making responsible everyday decisions;
- Understands how society influences science and technology as well as how science and technology influence society;
- Understands that society controls science and technology through the allocation of resources;
- Recognizes the limitations as well as the usefulness of science and technology in advancing human welfare;
- Knows the major concepts, hypotheses, and theories of science and is able to use them;
- Appreciates science and technology for the intellectual stimulus they provide;
- Understands that the generation of scientific knowledge depends upon the inquiry process and upon conceptual theories
- Distinguishes between scientific evidence and personal opinion
- Recognizes the origin of science and understands that scientific knowledge is tentative and subject to change as evidence accumulates;
- Understand the applications of technology and the decisions entailed in the use of technology;
- Has sufficient knowledge and experience to appreciate the worthiness of research and technological development;
- Has a richer and more exciting view of the world as a result of science education;
- Knows reliable sources of scientific and technological information and uses these sources in the process of decision making.

Figure 2-3. Attributes of a scientifically literate person, NSTA 1983
List appears in the NSTA Position Statement on Science-Technology-Society: Science Education for the 1980s (Brown and Butts, 1983).

The scientifically and technologically literate person:

- uses concepts of science and of technology as well as an informed reflection of ethical values in solving everyday problems and making responsible decisions in everyday life, including work and leisure
- engages in responsible personal and civic actions after weighing the possible consequences of alternative options
- defends decisions and actions using rational arguments based on evidence
- engages in science and technology for the excitement and the explanations they provide
- displays curiosity about and appreciation of the natural and human-made world
- applies skepticism, careful methods, logical reasoning, and creativity in investigating the observable universe
- values scientific research and technological problem solving
- locates, collects, analyzes, and evaluates sources of scientific and technological information and uses these sources in solving problems, making decisions, and taking actions
- distinguishes between scientific and technological evidence and personal opinion and between reliable and unreliable information
- remains open to new evidence and the tentativeness of scientific/technological knowledge
- recognizes that science and technology are human endeavors
- weighs the benefits and burdens of scientific and technological development
- recognizes the strengths and limitations of science and technology for advancing human welfare
- analyzes interactions among science, technology, and society
- connects science and technology to other human endeavors, e.g., history, mathematics, the arts, and the humanities
- considers the political, economic, moral, and ethical aspects of science and technology as they relate to personal and global issue
- offers explanation of natural phenomena which may be tested for their validity

Figure 2-4. Attributes of the scientifically and technologically literate person, NSTA 1990. This list appears in a statement prepared by the NSTA Task Force on STS Initiatives (Approved by the NSTA Board of Directors, July 1990; see Yager, 1993).

STS is not a single curriculum, but a general approach to learning about science and technology (Yager, 1996). Thus, the STS approach is not defined by specific content. Rather, the STS approach in the classroom usually begins with societal problems or issues (not traditional science topics) that are of interest or relevance to students and that are perceived to have connections to science (Foltz and Roy, 1991). Issues such as human cloning, biological weapons, pollution, where to place a local landfill, nuclear technologies, or global warming would fall under the rubric of an STS approach. Next, the associated "technologies are examined, and then the small amount of key science needed to be comfortable with analyzing the issues is introduced" (Foltz and Roy, 1991, p. 212). Finally, the relationships between science, technology, and society are examined, and potential solutions for the issue are addressed (Foltz and Roy, 1991).

This sequence (society technology science interactions of STS) represents an approach to science teaching that differs significantly from traditional methods (Bybee, 1987; Yager, 1996). For one thing, topics in a traditional science course usually reflect only one of the major disciplines of science, but STS topics are inter- and multi-disciplinary in nature (Bybee, 1987). STS students are expected to take personal responsibility for their learning (Bybee, 1987). The students are not passive listeners, but active participants in their own learning (Hurd, 1986). They think, evaluate risks, make decisions, experiment, use technologies, do research, write, report, discuss, and listen to one another, thus developing skills useful for their careers and life-long learning (Bybee, 1986; Yager, 1996). Students are often encouraged, though not required, to take action on an issue about which they feel strongly. Such individual empowerment and character development are important features of any STS unit (Foltz and Roy, 1991).

STS advocates claim that this approach prepares "all students to grapple successfully with science and technology in their own, everyday lives, as well as to participate knowledgeably in the important science-related decisions our country will have to make in the future" (Harms and Yager, 1981, p. 119). However, STS has also received its share of criticism. For example, Shamos (1995) says the "social" part of a particular issue is often allowed to dominate in the STS approach, so that technology and science get short-changed (Shamos, 1995). Furthermore, there may even be an "anti-technology" and "anti-science" bent to the instruction (Shamos, 1995).

STS has been difficult to implement on a wide scale for a number of reasons. The very fact the STS approach is non-traditional is one problem. Proposed changes in curricula have always been subject to much intense debate (Cremins, 1964; Ravitch, 1983). If done properly, STS requires small class sizes (Foltz and Roy, 1991). Small class sizes means more teachers and more rooms must be available, not an easy task for most schools.

STS is also difficult to teach because it is so multidisciplinary in nature (Fleming, 1986). Because STS lessons cross traditional discipline boundaries, teachers must feel comfortable in not being the expert ("sage on the stage") on all the topics discussed during a typical course (Yager and Lutz, 1995). Individuals fitting this description are rare. The teacher will certainly discover traditional teaching methods and resources do not work for the STS approach, especially since STS classes may be dominated by students who are not very interested in science (Foltz and Roy, 1991).

Even though STS is not universally pursued (or supported) in schools, many elements of the STS approach have "infiltrated" science education generally. The importance of connections between science and technology and science and society remain important themes of scientific literacy (AAAS, 1993; NRC, 1996). For example, both the Project 2061 reforms and the *National Science Education Standards* described later in this chapter contain references to STS tenets.

1983-2000: Period of 'Scientific Literacy as Reform'

In the late 1970s and early 1980s, the United States public became concerned by the emergence of Japan and other Asian countries as economic powerhouses. There seemed to be a general belief that "Our once unchallenged preeminence in commerce, industry, science, and technological innovation [was] being overtaken by competitors throughout the world" (National Commission on Excellence in Education, 1983, p. 5). These fears became particularly acute following the publication of *A Nation at Risk* (National Commission on Excellence in Education, 1983). The language and conclusions of this report were stark. Consider, for example, these quotes: "the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a nation and as a people" (p. 5), and "If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war" (p. 5). The report expressed a particular concern about high school students' lack of knowledge about science and mathematics. Within the same year, twenty bills were put before Congress to address this "crisis" in science education (Matthews, 1994). Before the decade was out, over 300 reports addressed the poor state of United States education (Hurd, 1989), many of them specifically discussing science (and mathematics) education (e.g., National Academy of Sciences, 1982; National Science Board, 1983). Many of these reports linked the nation's economic future to the public's (workforce) scientific and technological competence (e.g., Task force on Education for Economic Growth, 1983; Twentieth Century Fund Task Force, 1983). Many cited evidence that United States students were performing poorly in science and mathematics, both when compared to earlier decades and when compared with students in other countries (e.g., National Assessment of Educational Progress, 1983a; 1983b). Thus, general educational reform became "everybody's business," from policymakers to the business community to the public (Raizen, 1991, p. 26).

A "crisis in science education" was declared in the early 1980s (e.g., Brown and Butts, 1983; Bybee, 1982; Yager, 1982), reminiscent of the crisis generated by the *Sputnik* scare. However, a major difference between the two periods is the reform of science education in the 1980s "was clearly linked to the idea of scientific literacy" rather than an overwhelming focus on the science pipeline (Bybee, 1997, p. 59). Roberts (1983) had declared that the goal of scientific literacy "reached a point of maturity or, perhaps, exhaustion" by 1976. With the benefit of hindsight, I can now confidently declare that the goal of scientific literacy was certainly not exhausted but, in fact, just getting started. Many of the legislative bills and education reports during this period "urged the adoption of 'scientific and technology literacy for all' as the goal of school science instruction," with a great deal of emphasis being placed on the "for all" part (Matthews, 1994, p. 29). The reform proposals advocated

> the teaching of science more contextually; the curricula incorporate[d] the rich historical, philosophical, ethical, technical and social dimensions of science, presenting science as a more liberal enterprise than was the case in the professional and technical curricula developed in the 1960s. (Matthews, 1994, p. 35).

There was also a greater concern with equity: "a sound scientific and mathematical education was [seen as] a necessity for everyone, not just the èlite" (Raizen, 1991, p. 27).

In the 1980s, the individual states were more heavily involved than in the previous reforms, having acquired greater control of and responsibility for educational funding in the intervening years (Raizen, 1991). The state-initiated reforms had a "top-down" orientation, with policies and mandates originating from the state departments of education, state legislators, and the governors' offices (Raizen, 1991). Raizen (1991) asserts, "The rationale more often than not was an economic one, i.e., that a state's economic development and growth depended on the technical capabilities of its work force" (p. 27). One of the most widespread reforms to be implemented was an increase in the number of science and mathematics courses required for high school graduation (Raizen, 1991). In one case, Florida raised its requirements from no required science and mathematics courses at the beginning of the decade to 3 courses each by 1989

(Clune, 1989). Colleges and universities also increased their requirements for admission during the 1980s (Goertz and Johnson, 1985).

Accompanying the increased number of science classes required of students, almost all the states developed their own curricular guidelines for science by the end of the 1980s (Raizen, 1991). These guidelines varied widely in their content, specificity, and suggested or mandated practices for implementation (Raizen, 1991). Nevertheless, state curricular frameworks did seem to improve the quality and emphasis of science instruction in schools (Armstrong, Davis, Odden, and Gallagher, 1989).

Another reform initiative to sweep the nation during the 1980s was "a drive towards accountability through increased testing of student achievement" (Raizen, 1991, p. 29). Most states either initiated tests for reading, mathematics, and the language arts, or expanded the scope and stakes associated with previously mandated tests (Raizen, 1991). Some states also began testing in science, and more and more have added high-stakes science tests during the 1990s. An unfortunate outcome of the "test frenzy" was that in many classrooms the tests began to drive the curriculum rather than the reverse, i.e., teachers "taught to the tests" (Firestone, Fuhrman, and Kirst, 1989). I call this outcome "unfortunate" because standardized tests can measure only a limited amount of learning outcomes, largely rote knowledge, and they are often biased against minority students (Oakes and Lipton, 1999).

By the end of the 1980s, President George H. Bush and the Governors of the states set six national education goals for the next decade. These goals became law in 1994 (Goals 2000: Educate America Act, H.R. 1804). Several of these goals involve science education. In particular, Goal 4 states: "By the year 2000, United States students will be first in the world in mathematics and science achievement" (National Governors' Association, 1990).

Given its rise in prominence as an educational goal, it should come as no surprise that the literature related to scientific literacy "increased substantially" (Bybee, 1997, p. 59) during the 1980s. For example, the Spring 1983 issue of *Dædalus* (Journal of the American Academy of Arts and Sciences) was devoted to the topic of scientific literacy. It was here that Jon D. Miller first publicly presented a framework that he has used for two decades in several studies that measure the public's scientific literacy (see Miller, 1997). In broad outline, Miller conceptualizes scientific literacy as having 3 dimensions: (1) Understanding the Scientific Approach, or "the ability of the individual to read about, comprehend, and express an opinion on scientific matters" (Miller, 1983, p. 30); (2) Understanding Basic Scientific Constructs, or to be "learned" in science, i.e., to have "an understanding of the process or methods of science for testing our models of reality" (Miller, 1997, p. 124); and (3) Understanding of Science Policy Issues, or having a broad "public understanding of public policy issues—what Benjamin Shen ... characterized as 'civic science literacy'" (Miller, 1983, p. 32). In his 1983 article, Miller describes a project he led (funded by NSF) to measure the scientific literacy of members of the public, not just the school-age population, based on these 3 dimensions. He says that if one defines scientific literacy as a minimally acceptable score in all three of the dimensions of his survey, only 7 percent of the respondents qualified as scientifically literate (Miller, 1983). The level of scientific literacy increased with years of formal education, but even among those with graduate degrees only 26% were scientifically literate in all 3 dimensions.

In another article, "Achieving Wider Scientific Literacy," A. B. Arons (1983) offered a list of a 12 attributes of a "person who has acquired scientific literacy" (p. 92; Figure 2-5). Arons (1983) says his list is "neither exhaustive nor prescriptive," but merely "illustrates some of the insights that I believe characterize scientific literacy and that I find most college undergraduates, given time and opportunity, and having the willingness to exert some intellectual effort, can encompass" (p. 94). One of the most remarkable things about his list is the concentrated emphasis on aspects of the nature and procedures of science as hallmarks of scientific literacy.

The scientifically literate person should:

1. Recognize that scientific concepts ... are invented or created by acts of human intelligence and imagination ...
2. Recognize that ... terms require careful operational definition ...; to comprehend ... that a scientific concept involves an idea first and a name afterward, and that understanding does not reside in the technical terms themselves.
3. Comprehend the distinction between observation and inference ...
4. Distinguish between [serendipity] ... and the deliberate strategy of forming and testing hypotheses.
5. Understand the meaning of the word ‘theory’ in the scientific domain, and to have some sense ... of how theories are [used] ...
6. Recognize when questions such as ‘How do we know ...? Why do we believe ...? What is the evidence for ...?’ have been addressed, answered, and understood, and when something is being taken on faith.
7. Understand ... the [tentativeness] ... of scientific concepts and theories ...
8. Comprehend the limitations inherent in scientific inquiry ...
9. Develop enough basic knowledge and understanding in some area (or areas) of interest to follow intelligent reading and subsequent learning without formal instruction.
10. Be aware of at least a few specific instances in which scientific knowledge has had direct impact on intellectual history and on one’s own view of the nature of the universe and of the human condition within it.
11. Be aware of at least a few specific instances of interaction between science and society on moral, ethical, and sociological planes.
12. Be aware of very close analogies between certain modes of thought in natural science and in other disciplines ...

Figure 2-5. Arons (1983) list of attributes of the scientifically literate person

Most of the rest of the articles in the *Dædalus* issue do not explicitly define the term "scientific literacy," and about half do not even discuss it directly, but instead talk about various aspects of science education reform. This observation led the editor of the journal, Stephen R. Graubard (1983), to assert:

> Even the most casual examination of this issue of *Dædalus* will suggest that the term 'scientific literacy' lacks all precision, that there are no generally accepted criteria for determining what an individual needs to know to be called scientifically literate, or why it is vital (or even important) for great numbers of Americans to wish to achieve such literacy. Basic competence in science—another way of defining scientific literacy—is clearly an elusive concept, made all the more so by a fundamental ambiguity, even among educators, about the kinds of scientific knowledge and understanding that it is useful for ordinary citizens to command.

The fact that articles in an issue devoted to the topic of 'scientific literacy' do not define or refer to others definitions for the concept is evidence that it is mainly being used as an educational slogan by these authors (Scheffler, 1960).

Professional societies were also active in setting priorities and developing curricular guidelines in science during the 1980s and beyond. Of particular interest is the American Association for the Advancement of Science (AAAS). The AAAS is the world's largest scientific association. In the early 1980s, some members of this organization believed that by both national standards and world norms the United States education system was failing its students, and hence, failing the nation (AAAS, 1994). AAAS held a forum in 1989 to discuss the concept and state of scientific literacy in the United States. Several papers from the forum were later published in one volume of the *This Year In School Science* series (Champagne, Lovitts, and Callinger, 1989). The opening chapter (Champagne and Lovitts, 1989), entitled "Scientific literacy: A concept in search of definition," declares:

> Scientific literacy is the catch phrase of the educational discourse of the 1980s. National reports from the educational, governmental, and private sectors call upon the nation's schools to improve school science education and, as one consequence, stem the decline of the American economy. Although the reports agree that a scientifically literate citizenry is important to the nation, all fail to describe (in a way that enables measurement) what it means to be scientifically literate. (p. 1)

Champagne and Lovitts (1989) say that in part the disagreement on a definition stems from different people answering the question, "'What does it mean to be scientifically literate?'" in three different ways: some describe "the behaviors of scientifically literate persons in a variety of contexts"; others discuss "the mental state of a scientifically literate person—[the] knowledge, skills, and dispositions" of a scientifically literate person; and yet others make "references to educational experiences that are assumed to produce a scientifically literate person" (Champagne and Lovitts, 1989, p. 1). Even within one of these categories there can be considerable diversity and debate, and this "diversity and complexity of the behaviors, knowledge, intellectual skills, and dispositions considered to characterize the scientifically literate person also serve as barriers to achieving consensus" (Champagne and Lovitts, 1989, p. 3). For example,

> To some, being scientifically literate means the appropriate application of scientific knowledge and reasoning skills to solving problems and making decisions in one's personal, civic, and professional affairs. For others, being scientifically literate means the ability and inclination to continue learning about science lifelong. For still others, scientific literacy is often equated with being knowledgeable about science and having certain intellectual skills, whether they are used or not (Champagne and Lovitts, 1989, p. 3).

Furthermore, "the selection of the category—conditions of learning, mental state, behaviors—on which a definition [is] based … is also influenced by ideology"

(Champagne and Lovitts, 1989, p. 3). By ideology, Champagne and Lovitts (1989) meant “the images of the world that influence individuals’ social values and judgments’ (p. 4). For example, someone who esteems scientific knowledge “primarily for the pleasure it provides the individual” will have a different definition of scientific literacy than someone who values such knowledge “for its utility” (Champagne and Lovitts, 1989, p. 4).

Champagne and Lovitts (1989) constructed a visual representation of their framework (Figure 2-6), which they offer as a way to analyze “the conceptual barriers to achieving consensus on what constitutes scientific literacy” (p. 1).

Prior to the Forum, in early 1989, the AAAS conducted an informal national survey of “scientists, educators, teachers, students and science policy analysts” (Champagne and Lovitts, 1989, p. 5). The survey asked recipients “to rank 15 components of scientific literacy, with regard to the abilities that should characterize the typical high school graduate” (Collins, 1989, p. 136). The capabilities which received the highest ratings include:

- Read and understand articles on science in the newspaper.
- Read and interpret graphs displaying scientific information.
- Engage in a scientifically informed discussion of a contemporary issue, e.g., should a child with AIDS be allowed to attend public school.
- Apply scientific information in personal decisionmaking [sic], e.g., ozone depletion and the use of aerosols.
- Locate valid scientific information when needed. (Champagne and Lovitts, 1989, p. 6)

The capabilities contributing to scientific literacy that received the lowest ratings include:

- Provide a scientific explanation of a natural process, e.g., photosynthesis, digestion, combustion.
- Assess the methodology of an experiment.

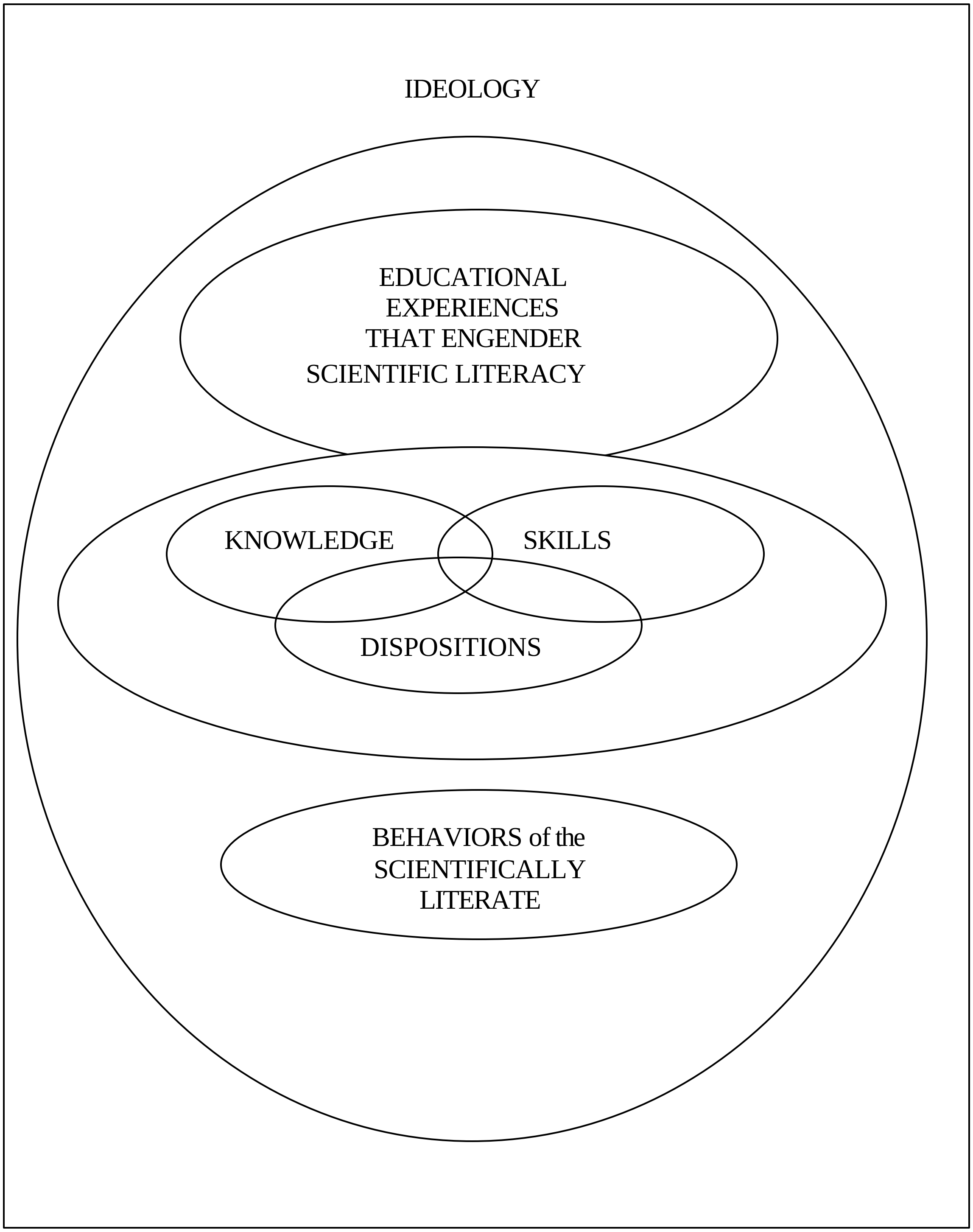


Figure 2-6. Champagne and Lovitts (1989) Conceptual Framework for Scientific Literacy.

- To define basic scientific terms, e.g., DNA, molecule, electricity.
- Design an experiment that is a valid test of a hypothesis.
- Describe natural phenomena, e.g., the phases of the moon. (Champagne and Lovitts, 1989, p. 6)

Intermediate ranked components included: “the abilities to pose a question that can be addressed by scientific methods, … [and] to envision science as worthy of pursuit even without immediate practical gains (Collins, 1989, p. 136). Collins (1989, p. 137) points out that what is missing from this list and “from all of the attempts to define scientific literacy [thus far] is an enthusiasm and excitement for knowledge about science.”

One interesting aspect of the survey results is that while the abilities to actually do science are included explicitly, they were in fact low-ranked. While *learning* science by *doing* science has been a mainstay in science education since the early alphabet curricula years (DeBoer, 1991), those surveyed did not seem to believe that the ability to do science after leaving school was of much importance. This conclusion points out more broadly that all those capabilities in the list above that received low-rankings might be considered ‘academic abilities,’ which “are not widely considered to be ends in themselves” (Champagne and Lovitts, 1989, p. 6). Rather, they are “necessary components of the capabilities rated essential to being scientifically literate” (Champagne and Lovitts, 1989, p. 6). For example, “it is not possible to understand a newspaper article about scientific issues … without knowing the meaning of the scientific terms used in the article” (Champagne and Lovitts, 1989, p. 6).

Angelo Collins (1989) developed a list of abilities that represent a minimal goal for science curricula to provide for elementary students. This list includes:

- observe and describe natural events
- pose questions about natural events
- explain natural events using scientific terms accurately

- recognize that the concepts that support those terms are human inventions and not immutable truths
- develop the skills required to describe, explain, and predict natural phenomena
- design experiments that test predictions about natural events
- develop the skills to work with other students to produce scientific descriptions, explanations, and predictions
- appreciate that scientific knowledge is constructed by people for people to describe, explain, predict, and control natural phenomena; and as such, it is complex and subject to change
- be comfortable enough with the ideas and procedures of science to follow a debate about a scientific topic in the media
- be aware of the influence of scientific knowledge on daily life and of daily life on science
- develop a lifelong enthusiasm for and excitement about knowledge of nature (pp. 129-130).

Collins (1989) bases these abilities on her view of the nature of science, which she describes as consisting of three components: structural, procedural, and human (Figure 2-7). The structural component has to do with "the knowledge products of scientific inquiry and the events on which these knowledge products are based" (Collins, 1989, p. 131), e.g., facts, theories, events, concepts, models, and principles. Procedural components are "skills to manipulate the elements of scientific knowledge," (Collins, 1989, p. 132), including inquiry skills, the 'scientific method,' problem-solving and critical thinking skills, and the mastery of the various "material tools" of science. The human component includes the ideas that doing science requires teamwork, that it is intra- and inter-disciplinary, it involves a reciprocal relationship with technology and society, and that it affects (and is useful in) daily life. Scientific literacy, then, is a combination of these three components. (Note, however, that for the purposes of Figure

2-7 I have only referred to Collin's list of elementary school abilities, and not to her three components of the nature of science.)

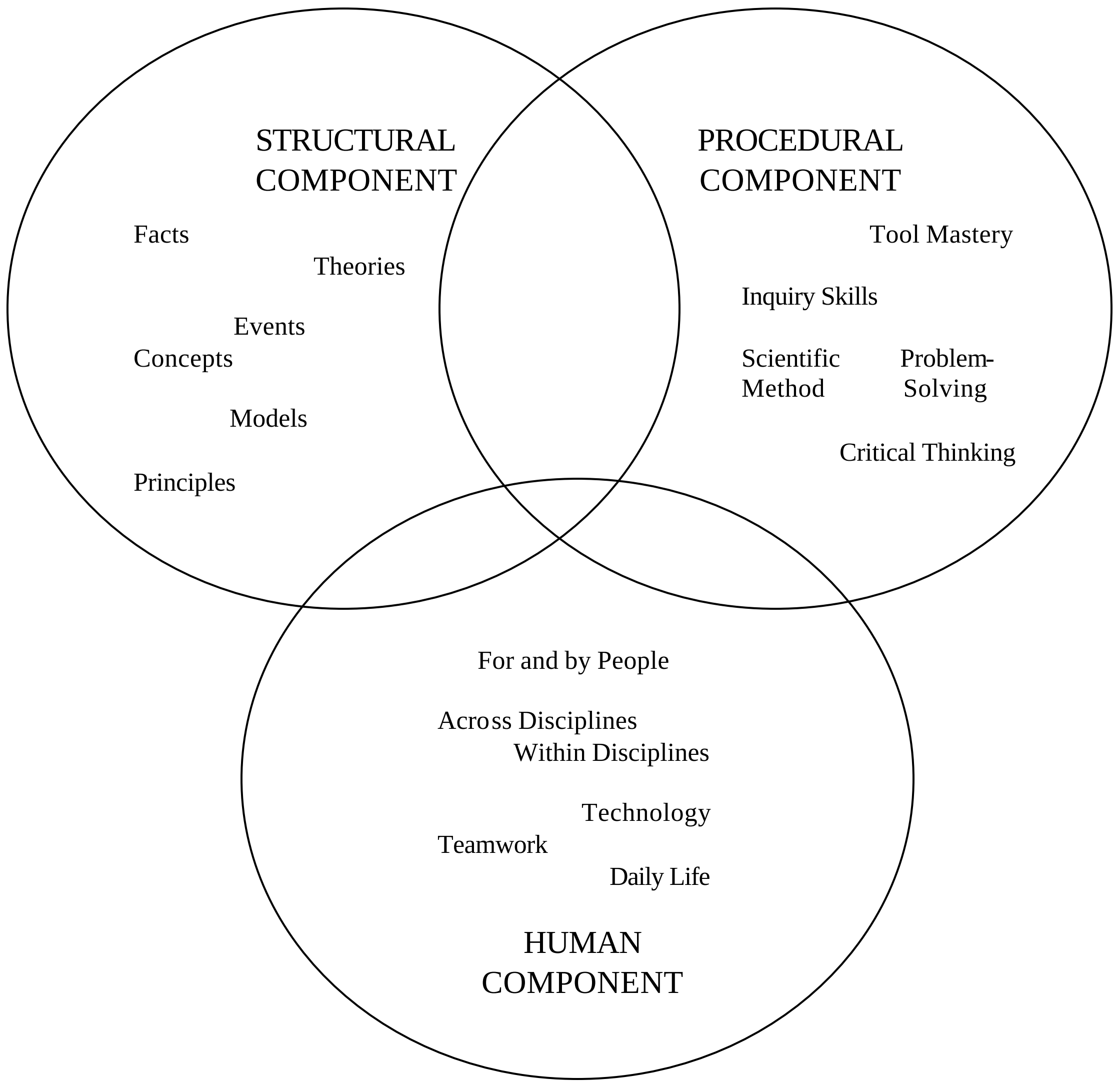


Figure 2-7. Collins's (1989) Components of Scientific Understanding.

Project 2061. As early as 1982, members of AAAS began to discuss and plan for a national effort to promote and stimulate ways to achieve widespread science literacy among American students (AAAS, 1994). In 1985, the AAAS organized several panels into the National Council on Science and Technology Education and entrusted this group with the program entitled "Project 2061." The title, "Project 2061," refers to the re-appearance of Haley's Comet (which was making a pass near the sun in 1985 when the Project began), and reflects the long-term nature of the undertaking. Five discipline-based panels of academics, teachers and administrators met over a three year period to discuss the question "Out of all the possibilities, what knowledge, skills, and habits of mind associated with science should all Americans have by the time they leave school?" (Matthews, 1994, p. 36).

The first public report of AAAS's Project 2061 appeared in 1989, the same year as the forum on scientific literacy. This report was quickly republished as a book, Science for All Americans (Rutherford and Ahlgren, 1990), or *SFAA* for short. *SFAA* consists of 12 chapters that can be grouped into 4 categories (Rutherford and Ahlgren, 1990, pp. ix-x):

- understandings of "the nature of science, mathematics, and technology—collectively, the scientific endeavor—as human enterprises."
- "basic knowledge about the world as currently seen from the perspective of science and mathematics and as shaped by technology."
- "understandings about some of the great episodes in the history of the scientific endeavor and about some crosscutting themes that can serve as tools for thinking about how the world works."
- "the habits of mind that are essential for scientific literacy."

SFAA uses a very broad conception of scientific literacy, and perhaps for the first time explicitly includes mathematics, technology, and the social sciences under that term. Even though *SFAA*'s view of scientific literacy is very broad, it claims that the overall amount of detail students are expected to retain is less than the discipline-oriented curricula of the 1960s and 1970s. Ideas and thinking skills are emphasized more than specific terms and procedures. Traditional boundaries between subject-matter categories are softened and connections are emphasized. Mathematics and technology concepts are intertwined with science concepts. *SFAA* also makes it very clear that scientific literacy is a goal for all students, not just the most capable. Nevertheless, some scholars criticize *SFAA* and later products of Project 2061 as still being too scientific and basically unrealistic in their expectations (e.g., Shamos 1995).

J. Preston Prather (1990) declared that "entering the 1990s, the science education profession still [lacked] a clear, philosophically justified definition of its boldly acclaimed goal, 'scientific literacy.'" For example, even though *SFAA* says it "is about scientific literacy" (pp. v), finding an explicit definition of that term in the report is not exactly easy. The Preface (pp. ix), states:

> *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 and scientific ways of thinking for individual and social purposes.

Later on, *SFAA* (p. x) says

> 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.

The reason *SFAA* is not more explicit about a definition is made clear by its "daughter" publication, *Benchmarks for Science Literacy* (AAAS, 1993), which explains that *SFAA* <u>is</u> the definition of science literacy: "*SFAA* answers the question of what constitutes adult science literacy, recommending what all students should know and be able to do in science, mathematics, and technology by the time they graduate from high school" (p. xi). In this view, the entire book is presented as the definition of the scientific literacy concept. However, in its "Vocabulary" section *Benchmarks* (p. 322) gives a much shorter definition for the term:

> **Science Literacy**. A literate person is an educated person, one having certain knowledge or competencies. But of course the rules keep changing with regard to precisely which knowledge and competencies define literacy—the ability to write one's name and read a simple prose passage long since having been replaced by more demanding requirements. In today's world, adult literacy has come to include knowledge and competencies associated with science, mathematics, and technology. Project 2061 has undertaken, in *SFAA*, to identify the knowledge and habits of mind that people need if they are to live interesting, responsible, and productive lives in a culture in which science, mathematics, and technology are central—that is, to describe what constitutes the substance of science literacy.
>
> People who are literate in science are not necessarily able to do science, mathematics, or engineering in a professional sense, any more than a music-literate person needs to be able to compose music or play an instrument. Such people are able, however, to use the habits of mind and knowledge of science, mathematics, and technology they have acquired to think about and make sense of many of the ideas, claims, and events that they encounter in everyday life. Accordingly, science literacy enhances the ability of a person to observe events perceptively, reflect on them thoughtfully, and comprehend explanations offered for them. In addition, those internal perceptions and reflections can provide the person with a basis for making decisions and taking action.

AAAS is not the only professional organization to become involved in science education reform during the 1980s and 1990s. Other projects included the Scope, Sequence, and Coordination project by the National Science Teachers Association (Aldridge, 1989), the *ChemCom* course developed by the American Chemical Society (1989) with NSF support, and the *National Science Education Standards* developed by the National Research Council (1996) at the National Academy of Sciences. The latter is of particular importance because of its intent to reform all aspects of science education at the pre-college level, and because it is often referred to by the participants of this study.

National Science Education Standards. In the late 1980s, the National Council of Mathematics Teachers published the "*Curriculum and Evaluation Standards for School Mathematics*" (NCTM, 1989). A standards movement subsequently swept through most of the school disciplines in the 1990s. In the early 1990s, the National Science Teachers Association decided to follow the lead of their mathematics colleagues and look into defining and achieving standards for scientific literacy. NSTA soon found that it could not undertake such a massive task alone, and so it turned to the National Academy of Science and the National Research Council [NRC] for help (NRC, 1996). Their combined efforts—along with the efforts of hundreds of educators, teachers, policy makers, etc. along the way—resulted in the publication of the *National Science Education Standards* (NRC, 1996) late in 1995. The *Standards* have "an explicit goal ... to establish high levels of scientific literacy in the United States" (p. 21). The *Standards* (NRC, 1996) document defines scientific literacy as

> 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,* <u>the content standards define scientific literacy</u>. [Emphasis added.]

> 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 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.
>
> Individuals will display their scientific literacy in different ways, such as appropriately using technical terms, or applying scientific concepts and processes. And individuals often will have differences in literacy in different domains, such as more understanding of life-science concepts and words, and less understanding of physical-science concepts and words.
>
> Scientific literacy has different degrees and forms; it expands and deepens over a lifetime, not just during the years in school. But the attitudes and values established toward science in the early years will shape a person's development of scientific literacy as an adult. (p. 22)

Thus, despite this already lengthy definition, the *Standards* (1996, p. 22) imply the definition is much longer by saying "the content standards define scientific literacy" (as I underlined above). The science content standards include:

- Science as Inquiry
- Physical Science
- Life Science

- Earth and Space Science
- Science and Technology
- Science in Personal and Social Perspectives
- History and Nature of Science

These standards are presented as grade-level bands (K-4, 5-8, and 9-12), and each section is several pages long. Therefore, it would be impractical for me to go into any further depth about their details here.

The *Standards* document expresses the view that the entire United States science education system is in need of reform. Therefore this document not only includes content standards for school curricula, but also standards for science teachers, professional development, assessment, science programs and the science education system generally. Collins (1995) says the *Standards* document has five "noteworthy characteristics" (p. 32):

- It is about all students understanding science, with the emphasis on understanding.
- It includes standards for content, teaching and assessment in a single document.
- The science content of the *Standards* is clearly distinguished from curriculum.
- It includes standards for the science education program and science education system.
- It underwent multiple forms of national review, but is not a consensus document because not all voices were heard (or listened to).

In addition, Collins (1995) notes that the *Standards* "introduces new problems into the science education system in the United States" (p. 33), including:

- There are concerns whether or not the science education system has the ability to make the changes called for in the *Standards*.
- In the struggle to replace coverage with understanding, the amount of science content in the *Standards* is reduced from what is found in many text books; this means teachers, who are in largely in control of the curriculum, must reconceptualize what it means to understand science.

- In order to pursue the vision portrayed by the *Standards*, new materials (textbooks, tests) must be produced, teachers must revise their instructional methods, and resources must be allocated in new ways. In addition, expectations for student achievement and for opportunity to learn science must be redefined.
- The tendency to place the responsibility for change on someone else must be overcome.

Collins (1995) notes that these standards should not be viewed as a static end point, but rather as a vehicle for reform that must also change over time. Although recent science textbooks claim to have incorporated the *Standards* into their associated curricula, it is still too early to determine the extent of impact of the *Standards* on the achievement of the goal of scientific literacy for all. However, an indication of the *Standards* widespread influence on science education may be seen in the number of publications referring to the document. For example, I once entered "National AND Science AND Education AND Standards" as keywords for an ERIC database search, and ERIC retrieved more than 600 documents published between 1995 and 2000 (On-line search, 9 May 2000).

Comparisons of the content (knowledge and understandings) in the *Standards* and *SFAA*/*Benchmarks* suggest there is 90% or more overlap (AAAS, 1997; Bybee, 1997). This congruence is no accident, as the introduction to the *Standards* makes clear: "The many individuals who developed the content standards section of the *National Science Education Standards* have made independent use and interpretation of the statements of what all students should know and be able to do that are published in *Science for All Americans* and *Benchmarks for Science Literacy*" (NRC, 1996, p. 15). There are several differences between these efforts (Bybee, 1997), including the fact that the *Standards* have a broader agenda than *Benchmarks*, since the former also includes standards for teaching, professional development, assessment, programs, and the educational system. However, one should note that Project 2061 has followed up *Benchmarks* with additional publications which address some of these aspects (e.g., AAAS, 1997).

Perhaps the most significant difference between *Benchmarks* and *Standards*, in my opinion, is that the *Standards* imply a scientifically literate person should be able to do science, whereas Project 2061 publications imply scientific literacy is mostly knowing some science and knowing *about* science. As evidence, consider that almost all the objectives stated in *Benchmarks* (AAAS, 1993) begin with the stem, "By the end of the [2nd, 5th, 8th, or 12th] grade, students should know …". Only one chapter (Chapter 12) says that students should be able to do or be inclined to use science. Chapter 12 is divided into 5 sections: Values and Attitudes; Computation and Estimation; Manipulation and Observation; Communication Skills; and Critical-Response Skills. The placement of all these skills and values in the last chapter that lists objectives for students in *Benchmarks* gives one the impression that such things are almost an afterthought, or at least not anywhere near as important as the previous 11 chapters on knowledge and understandings of science. In contrast, *Standards* places emphases on skills from the very first Content Standard for students: "As a result of activities in grades K-12, all students should develop understanding and abilities …" (NRC, 1996, p. 115). These remarks should not be interpreted as criticism or favoritism of either *Benchmarks* or *Standards*; I am simply pointing out that the views of scientific literacy portrayed by *Benchmarks* and the *Standards* are somewhat different.

Other Views in the late 1990s

Frank Sutman (1996) proposed a relatively simple definition for the concept of scientific literacy: "An individual is science literate when that person is able and willing to continue to learn science content, to develop science processes on his or her own, and able to communicate the results of this learning to others" (pp. 459-460). He says "Meeting the level of capability or readiness indicated by this definition does not depend upon any single specific body or amount of learned science knowledge or any specific level of ability to practice appropriate processes" (Sutman, 1996, p. 460). However, it is precisely this lack of specificity which makes Sutman's "definition" more like a slogan than a defined term. Sutman offered this "definition" in hopes it would represent "a reasonable or realistic goal for school-level science instruction" (Sutman, 1996, p. 460), but as Shamos (1995a), Kyle (1995a, b), and others might point out, expecting students to willingly learn science at school, much less to want to continue to learn science content after they have left school is hardly a realistic goal in United States society. How would one determine a person's willingness to learn science after formal schooling, or their ability to "develop science processes on his or her own"?

Perhaps another failing of Sutman's definition is the very fact that he was 'stipulating' a definition; by 1996, there were definitions enough for the term. Even so, he was not the last to do so. James Trefil (1996) also proposed another seemingly simple definition for scientific literacy in the same year: "a person is scientifically literate if he or she has enough of a background in science to deal with the scientific component of issues that confront him or her daily" (p. 543). It is important to remember that Trefil is one of the main promoters of the "cultural literacy" movement (Hirsch, Kett, and Trefil, 1987; Hirsch, Kett, and Trefil, 1993), which has as its major premise in order to be literate one must possess a sizeable vocabulary. As Trefil (1996) puts it, "Cultural literacy can be defined as that body of knowledge that educated people, in a given society, at a given time, assume that other educated possess" (p. 544). Trefil (1996) says, "Scientific literacy is actually a subset" of cultural literacy (p. 544). While Trefil's (1996) definition is in consonance with his earlier work, no doubt it will be rejected by many educators because of the ideology associated with it—not to mention its lack of functionality (see, e.g., Anson, 1988; Bizzell, 1988). What exactly does "background in science," or "deal with … issues" mean anyway? Rodger Bybee (1997) further argues the cultural literacy view of scientific literacy is an oversimplification: "scientific literacy should not be defined in this narrow sense, as the lowest level of functional literacy. Most would agree that we want—and expect—more than functional literacy from thirteen years of formal science education" (p. 72).

In *Achieving Scientific Literacy: From Purposes to Practices*, Rodger Bybee (1997) refutes Shamos' and others criticisms of scientific literacy, and promotes his vision and the reforms needed to accomplish the goal. Bybee says that, contrary to what Shamos' or anyone else believes, "claiming that scientific literacy has not been defined makes for engaging rhetoric, but the assertion is wrong" (Bybee, 1997, p. 70). Bybee (1997) traces the history of the term and its definitions over time. He notes "in many cases, the issue of accepting and using the term *scientific literacy* boils down to personal attitudes—what individuals like or don't like—and that is what ultimately determines its acceptance or rejection. It is much easier to use the term as a slogan and claim that it is seldom defined" (Bybee, 1997, p. 70). In response to "the perceived inadequacy of other perspectives, the apparent discrepancies of other definitions, and the general need to have a comprehensive, yet developmentally appropriate view of scientific literacy," Bybee (1997) provides a new framework ...that "presents scientific and technological literacy as a continuum in which an individual develops greater and more sophisticated understanding of science and technology" (p. 84; Figure 2-8). This model "assumes scientific and technological literacy are continuously distributed within the population" (Bybee, 1997, p. 82). Thus, different people have different "degrees of scientific literacy" (Bybee, 1997, p. 82), which range from illiteracy to nominal and functional scientific literacy, then to conceptual and procedural scientific literacy, and finally to multidimensional scientific literacy. Bybee (1997, p. 84) says "this framework functions as a taxonomy for extant programs and practices and as a guide for curriculum and instruction." A very important feature of Bybee's view is that it discounts the idea a person either is or is not scientifically literate; rather, everyone is scientifically literate to some extent. Bybee (1997, p. 116) maintains that the *Standards*, "specifically the Content Standards, combined with [his] framework for scientific literacy ... establishes a contemporary definition of scientific literacy that is clear, complete, and usable."

Illiteracy
A person who is scientifically and technologically illiterate cannot understand questions about science, or locate them within the domain of science or technology. This state may be due to age, stage of development, or developmental disabilities.

Nominal Scientific and Technological Literacy
In *nominal* literacy, the individual associates names with a general area of science and technology. However, the association may represent a misconception, naive theory, or inaccurate concept. The relationship between science and technology terms and acceptable definitions is small and insignificant. At best, students demonstrate only a token understanding of science concepts, one that bears little or no relationship to real understanding.

Functional Scientific or Technological Literacy
Individuals demonstrating *functional* level of literacy respond adequately and appropriately to vocabulary associated with science and technology. They meet minimum standards of literacy as it is usually understood; that is, they can read and write passages with simple scientific and technological vocabulary. Individuals may also associate vocabulary with larger conceptual schemes--for example, that genetics is associated with variation within a species and variation is associated with evolution--but have a token understanding of these associations.

Conceptual and Procedural Literacy
Conceptual and *procedural* literacy occurs when individuals demonstrate an understanding of both the parts and the whole of science and technology as disciplines. The individual can identify the way the parts from a whole vis · vis major conceptual schemes, and the way new explanations and inventions develop vis · vis the process of science and technology. At this level, individuals understand the structure of disciplines and the procedures for developing new knowledge and techniques.

Multidimensional Literacy
Multidimensional literacy consists of understanding the essential conceptual structures of science and technology as well as the features that make that understanding more complete, for example, the history and nature of science. In addition, individuals at this level understand the relationship of disciplines to the whole of science and technology and to society.

Figure 2-8. Bybee's (1997) Framework for Scientific Literacy (paraphrased from pp. 82-85)

Recently, Paul Hurd (1998) has once again weighed in on the scientific literacy debate. Hurd (1998) says that science today is very different from a few decades ago, and so our view of what constitutes scientific literacy must keep up with the changes. He also gives his latest definition of a scientifically literate person in a long list of attributes (Hurd, 1998, pp. 413-414; Figure 2-9). Among these attributes is "Recognizes that scientific literacy is a process of acquiring, analyzing, synthesizing, coding, evaluating, and utilizing achievements in science and technology in human and social contexts" (Hurd, 1998, p. 414). This statement sounds very much like a definition for scientific literacy in and of itself.

This review is not exhaustive of all the publications and events surrounding the goal of scientific literacy in the 1990s, but should suffice as representative of that decade. The reader may find Laugksch's (2000) discussion of conceptual definitions for scientific literacy of interest since he does not limit discussion to publications influential in the United States as I do in this dissertation. Laugksch does not describe his own definition of scientific literacy based on his research. Instead, he categorizes other's definitions into 3 groups, "Learned," "Competent," and "Able to function minimally as consumers and citizens." The knowledge and abilities required by the first two groups are made in reference to the scientific enterprise, whereas the latter refers to knowledge and skills required to function in society. The "Learned" category specifies no involvement with society and appears "to operate in a social vacuum" (p. 84), while the third category requires the "individual to use science in performing a function in society" (p. 84). The "Competent" category requires some interaction with society. The implication is that there are different purposes or rationales for each category of scientific literacy in this scheme, and by extension, different definitions of scientific literacy are very likely.

The scientifically literate person:

- Distinguishes experts from the uninformed.
- Distinguishes theory from dogma, and data from myth and folklore.
- Recognizes that almost every fact of one's life has been influenced in one way or another by science/technology.
- Knows that science in social contexts often has dimensions in political, judicial, ethical, and sometimes moral interpretations.
- Senses the ways in which scientific research is done and how the findings are validated.
- Uses science knowledge where appropriate in making life and social decisions, forming judgments, resolving problems, and taking action.
- Distinguishes science from pseudo-science such as astrology, quackery, the occult, and superstition.
- Recognizes the cumulative nature of science as an "endless frontier."
- Recognizes scientific researchers as *producers* of knowledge and citizens as *users* of science knowledge.
- Recognizes gaps, risks, limits, and probabilities in making decisions involving a knowledge of science or technology.
- Knows how to analyze and process information to generate knowledge that extends beyond facts.
- Recognizes that science concepts, laws, and theories are not rigid but essentially have an organic quality; they grow and develop; what is taught today may not have the same meaning tomorrow.
- Knows that science problems in personal and social contexts may have more than one "right" answer, especially problems that involve ethical, judicial, and political actions.
- Recognizes when a cause and effect relationship cannot be drawn. Understands the importance of research for its own sake as a product of a scientist's curiosity.
- Recognizes that our global economy is largely influenced by advancements in science and technology.
- Recognizes when cultural, ethical, and moral issues are involved in resolving science-social problems.
- Recognizes when one does not have enough data to make a rational decision or form a reliable judgment.
- Distinguishes evidence from propaganda, fact from fiction, sense from nonsense, and knowledge from opinion.
- Views science-social and personal-civic problems as requiring a synthesis of knowledge from different fields including natural and social sciences.
- Recognizes there is much not known in a science field and that the most significant discovery may be announced tomorrow.
- Recognizes that scientific literacy is a process of acquiring, analyzing, synthesizing, coding, evaluating, and utilizing achievements in science and technology in human and social contexts.
- Recognizes that symbiotic relationships between science and technology and between science, technology, and human affairs.
- Recognizes the everyday reality of ways in which science and technology serve human adaptive capacities, and enriches one's capital.
- Recognizes that science-social problems are generally resolved by collaborative rather than individual action.
- Recognizes that the immediate solution of a science-social problem may create a related problem later.
- Recognizes that short- and long-term solutions to a problem may not have the same answer.

Figure 2-9. Hurd's (1998) list of what a scientifically literate person should do

Criticisms of Scientific Literacy Goal

During the 1990s, several publications appeared that were somewhat critical of the goal of scientific literacy (e.g., Eisenhart, Finkel, and Marion, 1996; Jenkins 1990, 1992; Layton, 1991). Some educators, politicians, and members of the public believe that while the goal of universal scientific literacy is laudable, current efforts to implement it are not working. In part these beliefs are based on surveys of the public's knowledge of science, e.g., Miller (1992) found only 37% of the two thousand adults surveyed knew that human beings did not exist at the time of the dinosaurs, and only 26% knew that antibiotics do not kill viruses. Based on his surveys, Miller (1983, 1992, 1997) concludes that between five and nine percent of adult United States citizens are truly scientifically literate.

Secondary students' test scores on national and international tests are also used as evidence to claim that we are a nation of scientific illiterates. For example, compared with students in 20 other countries, twelfth grade United States students were near the bottom in their average scores on the Third International Mathematics and Science Study administered in 1995 (Takahira, Gonzales, Frase, and Salganik, 1998). A study by the National Assessment of Educational Progress found that 43 percent of twelfth graders could not perform at the Basic level of proficiency in science knowledge and skills (Bourque, Champagne, and Crissman, 1997). In addition, students from financially poor families and minorities generally score lower than their middle-class Caucasian classmates, and in some cases there are gender differences as well (Bourque, Champagne, and Crissman, 1997). In particular, unaddressed barriers to access and participation in school may be preventing females and minorities from becoming scientifically literate (Eisenhart, Finkel, and Marion, 1996). These barriers include such things as peer pressure against participating in school learning generally, and the traditional portrayal of science by teachers as a Western male activity. Furthermore, Eisenhart, et al. (1996) say that science educators have incorrectly assumed that increased knowledge of conventional science will automatically lead to greater use of science in a person's life, which is the "true" measure of scientific literacy. Instead, they say students need to be explicitly taught how to use science responsibly, an orientation that is not included in traditional school science courses.

In addition to those who criticize traditional practices as being insufficient to achieve scientific literacy, there are others who believe the goal needs to be clarified so it can be more fully realized (Laugksch, 2000; Roberts, 1983). As shown throughout the discussion of the history of science education above, one recurring criticism is that the term "scientific literacy" has no clear meaning, or perhaps more accurately, it has a multitude of viable meanings. As Brickhouse, *et al*. (1989) put it, even though "Everyone seems to agree that Americans should be scientifically literate and that the promotion of public understanding of science is a 'good thing' … "Definitions of scientific literacy are ubiquitous and elusive"(p. 157). Atkin and Helms (1993) assert that the broad goal of scientific literacy is actually a collection of many different aims or more narrow goals that have accumulated over time. In their view the meanings for "scientific literacy" have continually expanded rather than becoming more refined and focused. Kyle (1995a) revisited the issue of the meaning of the concept and states: "Until we have a greater degree of consensus as to what constitutes scientific literacy, it will be difficult to ascertain the degree to which we have been successful in achieving our goal!" (p. 896). He asks, "How many lost generations can we afford before we critically analyze what we mean by achieving scientific literacy?" (p. 896). Part of the confusion may stem from the fact that the parent terms, "science" and "literacy," themselves have no clear-cut meanings; both "literacy" (e.g. Graff, 1995) and "science" (e.g., Layton, 1991; Stanley and Brickhouse, 1994) mean different things in different contexts and to different people. Miller (1983) asserts that "To be literate has two quite different meanings: to be learned, and … to be able to read and write. Unfortunately, a good deal of the current debate about scientific literacy fails to distinguish between the two, and much of the confusion surrounding the issue can be traced to this omission" (p. 29). In fact, all concepts can have a variety of interpretations given that each person views the world in his or her unique way (Marton and Booth, 1997), so perhaps it should come as no surprise that different people interpret "scientific literacy" differently. Unfortunately, the (perceived) wide variety of views on the meaning of "scientific literacy" may not only inhibit communication related to the concept, but can have practical implications as well. For example, it is difficult to measure "scientific literacy" if the concept is not well defined (Li, 1999). Thus, the "vague, ill-defined" nature of the goal of scientific literacy may be one of the biggest obstacles standing in the way of its achievement.

The criticisms discussed so far all assume that scientific literacy is a valid goal, although the implementation of that goal is seen as falling short of the mark. However, an even more serious criticism is that scientific literacy may not be a legitimate goal at all. Longbottom and Butler (1999) say that the goal of trying to make everyone scientific literacy is "overambitious" and "unattainable," and ultimately it is even bad because its "unfulfilled expectations risk damage to the reputation of science and science education and open the way for the acceptance of irrational and unscientific notions" (p. 474). Morris Shamos (1995) claims that the goal of "scientific literacy for all" is too difficult to achieve given our present resources and the public's disinterest in learning science. He points out that despite decades of concentrated effort by science educators, the scientific literacy of the public has never been very high and is not improving (Shamos, 1995). Given that Shamos is scientific literacy's most vocal and radical critic, his criticisms and alternatives are more fully discussed below.

Criticisms by Shamos. The strongest critique of scientific literacy has been delivered by Morris Shamos (1995a) in his book, *The Myth of Scientific Literacy*. Dr. Shamos is professor emeritus of physics at New York University. He once served as president of the National Science Teachers Association. He has been involved in and published about science curriculum reform since the 1960s, including being a co-director of one of the “alphabet curriculum” programs for elementary schools (COPES) in the early 1970s (Shamos, 1995).

Shamos levels a number of criticisms against scientific literacy in his book and elsewhere (Shamos 1988a, 1988b, 1995b, 1996), and proposes this goal should be replaced with one he calls “science appreciation” or “science awareness.” For example, Shamos (1995a) criticizes the concept as being “ill-defined”, disapproves of the mechanisms by which science educators hope to achieve the goal, and—most importantly—he questions the value of the goal itself. He charges that the explicit goal of universal scientific literacy does not accord with the values science educators implicitly endorse. Shamos (1995a) states, “The need for widespread scientific literacy has been rationalized on several grounds, but when carefully probed most have a hollow ring to them” (p. 91). The actual goal of science educators, so Shamos (1995a) alleges, is to perpetuate their careers and interests. Thus, Shamos (1) challenges the validity of the espoused rationales for universal scientific literacy; and (2) alleges that science educators have a hidden agenda that does not match their explicit goal.

First, Shamos (1995) says science is not necessary for everyone to know in either their public or private lives. Science educators claim there are many science-based societal issues that frequently affect the public, such as nuclear energy, depletion of genetic resources, genetic engineering, and so forth. Shamos points out that these issues are actually more related to technology than science. He maintains “the list of societal issues that are truly science based is very short indeed, encompassing mainly such questions as federal funding for research (e.g., space probes ... the Human Genome project), or whether certain types of scientific research should be discouraged, or even prevented (e.g., animal experimentation, genetic engineering, human gene transplants)” (Shamos 1995, p. 147). Furthermore, concerning public decisions about any of these issues, Shamos claims, “we really do not need *total* scientific literacy to profoundly alter the way that society deals with technical matters” (Shamos 1995, p. 196). Instead, he calculates that "if our national scientific literacy rate ... were in the order of 20 percent ... the chance of finding one or more such individuals in almost any deliberative group would become a near certainty" (Shamos 1995, p. 195). The scientific literate person in the deliberative group could persuade the others of the merits or perils of the proposed project, according to Shamos, thus ensuring that a scientifically sound decision is reached.

Shamos (1995) says that if there is any truth to the

> popular argument generally offered ... that [scientific literacy] better prepares a nonscientist to function in business or professional life ... students fail to perceive it, and small wonder: they need only look at their own professional family members and friends, at wealthy businessmen and powerful public officials, at people in the arts and entertainment and professors of humanities--all successful and respected members of society and most, if not all, illiterate in science. After all, what bearing does a lawyer's *understanding* of the double helix have on the success of his practice? How many times does a banker call on the uncertainty principle to make an investment decision? Is it necessary for the mayor of New York ... to be versed in plate tectonics to run City Hall, or for a surgeon doing laser surgery to understand the physics of lasers? Would a knowledge of chaos theory have boosted the careers of Luciano Pavarotti or Laurence Olivier? The same question might be asked of all educated adults in the work force, with essentially the same answer: there is no convincing evidence that *understanding* science is important to them. While enjoying the everyday comforts and benefits derived from science and technology, society has managed to insulate itself from any actual or even perceived need to understand their origins. (pp. 97-98)

Shamos concludes, "The sad but simple fact is that one does not need to be literate in science ... to be successful in most enterprises or to lead the 'good life' generally" (Shamos 1995, p. 98).

Thus, Shamos brings into question the real value of the overt rationales for the goal of universal scientific literacy. He also goes further by claiming that the explicit reasons given for pursuing the goal of universal scientific literacy are not in accord with the actual practices of science educators. Shamos says that the avowed purpose of science educators--to increase scientific literacy among all students and the public--is actually a front for their “primary” purpose, namely, “to ensure a steady supply of scientists and science-related professionals, including, of course, science educators” (Shamos 1995, p. 73). Shamos (1995) says there never was an educational “crisis” in science education, as was alleged in the 1980s, but that this declaration was a ruse to dupe the federal government into greater funding for science and science education programs. The ruse worked so well, he claims, that “scientific literacy has become too good a public relations ‘prop’ for the science education community to abandon at this point. It has served the community well as the rationale for increased support for science education” (Shamos 1995, p. 158). In other words, science educators think they owe their jobs to the explicit goal of universal scientific literacy, and so must keep their implicit goal of perpetuating science and science-related programs quiet, or else they risk losing their livelihoods.

Shamos (1995) further alleges that universal scientific literacy is not achievable. “For the simplest proof” of this fact, “one need only consider the current intense activity surrounding science education [today]--a clear admission that even a modest solution is yet to be found” despite a half century of enormous effort (Shamos 1995, p. 160). He estimates that only about 5 percent of the American public is truly scientifically literate; Shamos cites Jon Miller’s “Longitudinal Study of American Youth” as supporting his claim for the low scientific literacy rate (see Shamos, 1995, p. 90).

Shamos (1995) claims, “never in United States history has there been a time when the public at large, or even its highly educated segment, could be considered literate in science” (p. 158). The reason, according to Shamos (1995), “is that becoming and remaining reasonably literate in science requires a special effort on the part of students, a commitment that very few non-science students are prepared to make. Science is not easy--there is no getting around this--and the more we try to simplify it the more we find ourselves moving away from those areas that comprise the essence of true scientific literacy" (p. 94). Thus, we have failed, and will continue to fail, to achieve universal scientific literacy because learning science is "hard" (Shamos, 1995, pp. 95-97).

Furthermore, Shamos (1995) claims that even those students who could learn science do not do so because they do not want to learn it--they do not see the benefits as justifying the effort. As explained earlier, Shamos argues the students believe scientific understanding is not necessary for admission to college, a good job, or self-fulfillment. To state this differently, most people (young and old alike) do not perceive scientific literacy as relevant to their adult lives. Even if students could be made scientifically literate, they would lose this literacy once they graduate because there is little need or, indeed, little chance to use their scientific understanding in their lives. It is adults, not students, that need to be scientifically literate, Shamos (1995) argues, so efforts to promote scientific literacy would be more effective if targeted at a post-high school audience.

Shamos (1995) says another reason the goal of scientific literacy for all cannot be achieved is because the concept is not well defined. Shamos (1995) states that the "seemingly endless 'reforms' in science education" during the last half century are evidence enough that

> there is no consensus on what 'scientific literacy' means or should mean. Instead, everyone involved with science education appears to have a vague, ill-defined notion of what it should mean, ranging from the simplistic view that any exposure to science contributes something to the state of mind called 'scientific literacy,' to the equally naïve view that scientific literacy means being able to think like a scientist. (p. 160).

Shamos (1995) further points out that not only has there been some disagreement in the past about the exact definition of scientific literacy, but the definitions have changed somewhat over the years leading to even more confusion. Personally, he defines 'true' scientific literacy as follows (Shamos, 1995, p. 89):

> At this level the individual actually knows something about the overall scientific enterprise. He or she is aware of some of the major conceptual schemes (the theories) that form the foundations of science, how they were arrived at, and why they are widely accepted, how science achieves order out of a random universe, and the role of experiment in science. This individual also appreciates the elements of scientific investigation, the importance of proper questioning, of analytical and deductive reasoning, of logical thought processes, and of reliance upon objective evidence.

Shamos (1995) says that an individual obtains 'true' scientific literacy only by passing through two other levels of scientific literacy in sequence. The first is "cultural scientific literacy," by which he means the individual knows several hundred science-related terms and their definitions (see Brennan, 1992; Hirsch, Kett, and Trefil, 1987, 1993). Using this "lexicon," the individual can "recognize many of the science-based terms (the jargon) used by the media, which is generally their only exposure to science, ... but for the most part this is where their knowledge of science ends" (Shamos, 1995, p. 88). An individual can, however, attain the next level, "functional scientific literacy," by learning to "converse, read, and write coherently, using such science terms in perhaps a non-technical but nevertheless meaningful context. This means using the terms correctly ...[and] knowing what might be called 'some of the simple, everyday facts of nature'" (Shamos, 1995, p. 88). For Shamos, one of the key aspects of this level is a functionally literate person "should be able to engage in a meaningful discourse on most science articles that appear in the popular press" (Shamos, 1995, p. 89). Shamos (1995) estimates the number of Americans at this level as 30% or less of the public.

Another problem associated with the “vague, ill-defined” nature of scientific literacy, according to Shamos (1995) is there is no good way to measure it. He states (p. 170): “Testing for factual knowledge is simple and straightforward, and therefore is all that is done in most instances. But this is not the answer, for we know that facts alone, while necessary, do not constitute the essence of science and are certainly no measure of literacy in the subject”. Shamos suggests that “any competent scientists or science educator, following a brief conversation with an individual, should be able to recognize whether that person is either totally illiterate in science or, as is more likely, knows something about science.” The problem is “it is [clearly] impractical to evaluate all individuals in such a one-on-one manner” (p. 171).

Shamos (1995) therefore concludes “that no reasonable amount of effort” can achieve “the utopia ... in which all educated men and women speak the language of science,” at least not in the foreseeable future (p. xvi). He suggests, “perhaps it is time to give up the idea that such literacy can be achieved merely by exposing all students to some form of compulsory science education, rigorous as that might be made, and hoping that enough of it sticks with them to make us a scientifically literate nation. If the past is any harbinger at all of the future, we have no reason to believe that this is feasible” (Shamos, 1995, p. 191).

One way to attack someone else’s idea is to propose an alternative to it. Shamos proposes the goal of “science appreciation” or “science awareness” as a more appropriate and attainable goal for science education today in the United States. He traces this idea, in part, to Edward Teller, the physicist and hydrogen bomb expert, who, in the 1950s, “likened the need for public support of science to that of the arts” (Shamos, 1995, p. 197). Shamos (1995) says that Teller’s message of science appreciation courses for our children “fell on deaf ears” (p. 198) because of our space race with the Soviets--the Congress and American public believed scientific literacy was a more appropriate goal, giving the military/security aspect of science and education precedence over other aspects. However, Shamos (1995) maintains that then, and now, “the science and engineering communities, and our nation generally, would be better served by a society that, while perhaps illiterate in science in the formal academic sense, at least is aware of what science is, how it works, and its horizons and limitations” (p. 198).

Shamos (1995) shies away from calling his goal science “appreciation” because the term “has the twofold connotation of gratitude and awareness” (p. 199). He suggests “a better term, ... would simply be ‘science awareness’” (p. 199). Special courses might be one way to facilitate this goal “if a real effort were made to develop an effective curriculum toward this end and one had a clear idea of what should be meant by” science awareness (Shamos, 1995, p. 199). Shamos (1995) says that it is clearly unreasonable to expect most people to come “to see the beauty in science” or “to expect the general student to attain a level of understanding in science that would permit the future adult to reach truly independent judgments on societal issues having a scientific base” (p. 200). Therefore, we “must learn to rely on scientific experts for advice” (Shamos, 1995, p. 200) just as we do in medicine, law, and other highly specialized fields. Shamos (1995) summarizes is position like this:

> one objective of general education in science, perhaps the most important one in the eyes of the scientific community, must be to encourage such an appreciative audience, one that at least understands how and why so much needs to be spent of science and technology, even apart from military requirements, to keep pace with the developing world. Another objective, probably more important to society at large, must be to help the student, and society generally, feel more comfortable with new developments in science and technology. They need not so much to understand the details but to recognize the benefits--and the possible risks. In principle, this could be accomplished in two ways. The obvious way, of course, is by developing in the student true (and lasting) scientific literacy, which, we have seen, is an impossible task for all but a very small fraction of

> the population. The other is by helping the public to gain confidence in the individuals, public interest groups, and governmental agencies that control the funding of science and technology, and in an important sense regulate the interface between technology and society. (p. 201).

Shamos (1995) outlines a "curriculum guide for scientific awareness" that changes the emphasis from science content "to the process of science, continually stressing technology" (p. 223). He summarizes his proposed procedure as follows:

> (a) introduce *all* topics through some relevant problems or issues in technology, but only where these are meaningful to student; (b) work back to the underlying science where, and only to the extent, it is needed to account for the technology; (c) use the underlying science, where appropriate, as a springboard to discuss the nature of the scientific enterprise—namely, the role of experiment and the meaning of scientific truth, facts, laws, theories, etc.; (d) return to technology, again where appropriate, as the basis for discussing the science/society interface; and finally (e) conclude with when and how to use expert advice at the science/society interface. (pp. 225-226).

Shamos (1995) advocates that "quantitative analysis must be kept to a minimum" and "the pure science portion of the curriculum ... should be kept to a bare minimum," (p. 226) as well. The nature of the scientific process is to be stressed, and all the while the meaningfulness of the subject matter to the student must take precedence over disciplinary considerations.

To summarize, Shamos' (1995) arguments against the goal of scientific literacy can be outlined as follows:

1. The term "scientific literacy" is "vague" and "ill-defined" so that anyone can put his or her own gloss on the concept.
2. The goal is not achievable (by current means) due to the following factors:
    - It is impossible to learn all of the content of modern science.

- Learning science is hard, due to its cumulative nature, reliance on mathematics, and discord with common sense.
- There is little motivation for students to become scientifically literate, and without this motivation the goal cannot be achieved. (See #3)

3. Becoming scientifically literate is not necessary.
   - It is not perceived as necessary by the students or the public. Therefore, progress towards the goal is chancy at best.
   - It is not actually necessary. If only 20% of the public were scientifically literate, the chances of having a science literate person in any given deliberative group are virtually 100%.
   - The "facts" or claims purported to support the goal "have a hollow ring to them." There is no clear evidence that science literacy gives one a better career or life.
   - Arguments used to promote the need for science literacy are actually better arguments for technologic literacy.
4. It is not practical to measure scientific literacy for large groups, so we could not operationalize a consensual definition even if we had one.
5. Scientific literacy is more important for adults than for young people, yet nearly all efforts to achieve scientific literacy ignore the adult population.

In addition, he claims scientific literacy is a front for science educators' true goal of perpetuating their own careers and keeping the science pipeline flowing. The cry of "scientific illiteracy" is used mainly as a slogan to get more funds for curriculum programs and research.

Summary

This chapter has examined the historical context of the concept and goal of scientific literacy as it relates to reform efforts in science education during the latter half of the Twentieth century. I have shown that the term ‘scientific literacy’ was first coined in 1952 (Conant, 1952), and that there have been numerous papers published about the concept since that time. The goal particularly became prominent in the 1980s and 1990s because it closely reflects the values of science education reform more generally, i.e., to ensure that all students have the opportunity to receive a quality science education experience.

The historical review was followed by an examination of some of the criticisms of the concept and goal, especially the views of Morris Shamos. It is my belief that if these criticisms are not addressed, they may mount and have serious repercussions for the goal (and all of science education) in the future.

CHAPTER 3

RESEARCH METHODS

Introduction

In an effort to critically re-examine the goal of scientific literacy, this interpretive study examines meanings and rationales associated with the term 'scientific literacy' as espoused by 9 university science educators. In this chapter, I describe the study's philosophical and methodological theoretical framework, as well the qualitative methods used to gather and analyze data. I also explain the verification procedures employed to ensure the trustworthiness of findings, i.e., what traditional research labels "validity" and "reliability." Next, I discuss my perspectives and assumptions, including my personal motivation for conducting this study, and I give a brief description of how the project evolved over time. Finally, I discuss some delimitations and limitations of the study.

Philosophical Framework

This study is based on the interpretive (or qualitative) research tradition in science education (Erickson, 1986; Gallagher, 1991a). Qualitative researchers approach their studies with a basic set of beliefs or assumptions related to philosophical issues, including such questions as "what is the nature of reality," and "what can we know about it?" Table 3.1 summarizes 5 philosophical assumptions of qualitative research with implications for practice. The first assumption, the ontological issue, addresses the qualitative researcher's beliefs about the nature of reality. Qualitative researchers believe that there are multiple, subjective realities (Creswell, 1998; Guba and Lincoln, 1988; Spector and Glass, 1991). The belief that each individual constructs his or her own notions about reality implies that one should expect participants to view the same phenomenon differently. In the case of this particular study, then, I began with the expectation that each individual would have his or her own unique views about the goal of scientific literacy. My challenge was to find evidence of their different perspectives, and to compare and contrast their views to see if their different "realities" have meaningful implications for the practice of science education in the United States.

Table 3.1
Philosophical Assumptions of Qualitative Research with Implications for Practice (from Creswell, 1998, p. 75).

Assumption	*Question*	*Characteristics*	*Implications for Practice (Examples)*
Ontological	What is the nature of reality?	Reality is subjective and multiple, as seen by participants in the study	Researcher uses quotes and themes in words of participants and provides evidence of different perspectives
Epistemological	What is the relationship between the researcher and that being researched?	Researcher attempts to lessen distance between self and that being researched	Researcher collaborates, spends time in field with participants, and becomes an "insider"
Axiological	What is the role of values?	Researcher acknowledges that research is value laden and that biases are present	Researcher openly discusses values that shape the narrative and includes own interpretation in conjunction with interpretation of participants
Rhetorical	What is the language of research?	Researcher writes in a literary, informal style using the personal voice and uses qualitative terms and limited definitions	Researcher uses an engaging style of narrative, may use first-person pronoun, and employs the language of qualitative research
Methodological	What is the process of research?	Researcher uses inductive logic, studies the topic within its context, and uses an emerging design	Researcher works with particulars (details) before generalizations, describes in detail the context of the study, and continually revises questions from experiences in the field

Although qualitative researchers may study documents and other physical artifacts, their primary goal is to minimize the "distance" between self and those being researched (Guba and Lincoln, 1988, p. 94). This epistemological belief implies that the qualitative researcher attempts to interact with those they study (Creswell, 1998), as I have done by interviewing participants and socially interacting with them (e.g., at conferences and via e-mail).

Traditional quantitative studies are based on the belief that the researcher must attempt to be "objective," i.e., that the knowledge being sought is free of values imposed by the researcher (Guba and Lincoln, 1988). Qualitative researchers, on the other hand, assume that the study is value-laden (Creswell, 1998; Guba and Lincoln, 1988). Qualitative researchers act on this axiological issue by reflecting upon and then clarifying their values (beliefs, assumptions and biases) throughout the study, and also by making their values clear to the audience of the study. I have attempted to make my own biases clear in this narrative, e.g., in the later section "Researcher Perspectives and Assumptions."

Creswell (1998) identifies the "rhetorical assumption" of qualitative research as meaning that the "investigator uses specific terms and a personal and literary narrative in the study" (p. 77). This belief implies that the qualitative researcher writes in a more literary and informal style than that of traditional research papers, and the personal voice (including first-person pronouns) is often used (Creswell, 1998). The qualitative investigator also uses terms in a different way, e.g., one usually does not "see an extensive 'Definition of Terms' section in a qualitative study because the terms as defined by informants are of primary importance" (Creswell, 1998, p. 77). Some terms used in traditional quantitative research are not used or they have counterparts in quantitative research, e.g., "instead of terms such as <u>internal validity</u>, <u>external validity</u>, <u>generalizability</u>, and <u>objectivity</u>, the qualitative researcher … may employ terms such as <u>credibility</u>, <u>transferability</u>, <u>dependability</u>, and <u>confirmability</u> (Creswell, 1998, p. 77, based on Lincoln and Guba, 1985).

From all the forgoing philosophical issues emerge the methodological assumptions of qualitative research. These assumptions include that the research begins inductively, although it may secondarily involve deductive logic (Strauss and Corbin, 1990); that the design of the study emerges and develops over the course of the research rather than being 'set in stone' at the beginning (Bogdan and Biklen, 1992; Creswell, 1998; Guba and Lincoln, 1988; Lincoln and Guba, 1985); and that the context of the topic being studied is extremely important and should be described from the general to the specific (Creswell, 1998). Thus, in this study I employed the constant comparative method of data analysis (Strauss and Corbin, 1990) in order to inductively derive models and hypotheses about participants' views on the concept of scientific literacy. The questions being researched changed over the course of the study, and most of the participants interviewed (as well as documents examined) were selected as the study progressed rather than *a priori*. And in the remainder of this chapter, as well as throughout the dissertation, I attempt to set the study into its historical and contemporary context, as well as my own personal context.

In the next section on research methods, I will further elaborate on the qualitative/interpretative tradition in educational research, and I will specifically describe the methodology that guided my study.

Methodological Theoretical Framework

Qualitative (or interpretive) research is based on the assumption that there are multiple, subjective "realities" which are individually and socially constructed (Spector and Glass, 1991). The aim of qualitative research is to study the way people respond to the world, as they perceive it. Qualitative research has the following characteristics (Bogdan and Biklen, 1992; Creswell, 1998; Merriam, 1998; Spector and Glass, 1991):

- A natural setting is the source of the data, as opposed to a laboratory
- The researcher is the key instrument of data collection, not a machine or questionnaire

- Data are collected as words or pictures, rather than as numbers; the data collected are initially descriptive
- The outcome focuses on processes rather than products
- Primarily, data are analyzed inductively, with attention to particulars (deduction is also involved, though secondarily).

Questions and procedures may evolve or emerge from the data in qualitative research. That is to say, theories and hypotheses are often generated by, rather than being used *a priori* by, qualitative research (Spector and Glass, 1991).

The qualitative researcher in science education usually does not intentionally manipulate the participants or environment. Rather, qualitative researchers focus on the participants' perspectives, and on understanding the meanings they give to phenomena. The researcher's perspective may be included, but it is made explicit and is rarely the sole focus of the research (Spector and Glass, 1991). The latter point is especially important for it again reflects the key philosophical assumption upon which all types of qualitative research are based, namely, "the view that reality is constructed by individuals interacting with their social worlds" (Merriam, 1998, p. 6).

It is important to note there are exceptions to these generalizations, i.e., a particular qualitative research study may not include all of these elements (Spector and Glass, 1991). Different researchers may emphasize certain elements and exclude others, or may even have antithetical elements to those listed here depending on the qualitative research tradition they are using and the problem they are investigating (Spector and Glass, 1991).

My study was particularly amenable to a qualitative research design because I was seeking to ascertain the subjective perceptions of science educators. I did not assemble variables to manipulate or numbers to 'crunch'. Rather, I gathered data in the form of interviews and documents so that I could obtain science educators' perspectives. Then I analyzed these data and identified what I perceived to be recurring patterns, or categories, which explain the data. Although this study is exploratory in nature, I sought to build general hypotheses or theoretical statements about science educators' beliefs concerning scientific literacy as a goal, following the constant comparative method of grounded theory (Strauss and Corbin, 1990). It is important to note that as with any qualitative study involving a small sample size, I do not intend for the results here to be construed as fully representative of the science education community as a whole (see the section on "Verification Procedures"). Any hypotheses I put forth here should be viewed as tentative and subject to change as more studies are conducted.

Data Construction and Analysis

In the attempt to inductively derive themes about science educators' views of the goal of science literacy, data for this study were analyzed using the constant comparative method (following Strauss and Corbin, 1990). My data primarily consist of interview transcripts from personal interviews, although I also have some written interviews and other documents that also serve as data. Therefore, in the following section I outline the constant comparative method of data analysis, and then I discuss the selection of interview participants, some issues surrounding the interview process, and my search for and selection of documents related to scientific literacy.

Constant Comparative Method

I used the constant comparative method of data analysis for developing a grounded theory (Strauss and Corbin, 1990). "Constant comparison" means that as data are examined, the researcher constantly makes comparisons between the data and other things that are known, and also continually asks questions about the data and the analysis itself (Glasser and Strauss, 1967; Strauss and Corbin, 1990). Data analysis was by no means a simple, linear, step-by-step process (Merriam, 1998). Rather, data gathering, data analysis, and narrative report writing often proceeded simultaneously.

The primary sources of data for this study are transcripts of interviews I personally conducted with the 9 study participants. As I read the transcripts, I begin to code or label the data. "Coding" means identifying bits of data that seem relevant to the study and giving them names. This procedure is a way of "conceptualizing" the data, i.e., "taking apart an observation, a sentence, a paragraph, and giving each discrete incident, idea, or event, a name, something that stands for or represents a phenomenon" (Strauss and Corbin, 1990, p. 63). Thus, as transcripts and documents are read, "you jot down notes, comments, observations, and queries in the margins ... next to bits of data that strike you as interesting, potentially relevant, or important to your study" (Merriam, 1998, p. 181). The researcher then groups comments and notes that seem to go together, thus generating the initial "categories" of the study (Merriam, 1998). The researcher continues to compare the notes derived from one transcript or document with those of the next, and merges them "into one master list of concepts" (Merriam, 1998, p. 181).

Strauss and Corbin (1990) refer to the development of categories in this initial coding cycle as "open coding." Categories are simply conceptual constructions that capture recurring patterns in the data (Merriam, 1998). Categories span different sources of data, and are not the data themselves (Merriam, 1998). The categories describe the data and to some extent interpret it (Merriam, 1998). Merriam (1998, pp. 183.184) recommends several "important guidelines" for determining the efficacy of categories:

- Categories should reflect the purpose of the research.
- Categories should be exhaustive, i.e., cover the preponderance of the data.
- Categories should be mutually exclusive.
- Categories should be sensitizing, meaning they should capture the meaning of the phenomena as closely as possible.
- Categories should be conceptually congruent, i.e., all at the same level of abstraction.

Merriam (1998) also recommends that categories should be few in number, representing a high level of abstraction. If there are a large number (10+) of categories, this may "reflect an analysis too lodged in concrete description" (Merriam, 1998, p. 185).

In essence, then, a researcher goes over his or her data repeatedly, searching for categories that fit the criteria above. The characteristics or attributes of a category, often called its *properties*, are also developed and described to represent multiple perspectives about each of the main categories (Creswell, 1998; Strauss and Corbin, 1990). These properties are then "dimensionalized," i.e., they are located along one or more continua (Strauss and Corbin, 1990). For example, suppose the category is "watching." Properties of watching might include the "frequency" and "duration" of watching. The dimensional range of frequency might be from "never to often," while a dimension of duration might be from "short to long" (Strauss and Corbin, 1990). Identifying the properties and dimensions of categories not only helps the researcher to understand the category, but also aids in identifying the relationships between categories (Strauss and Corbin, 1990).

At this point, the categories "have a life of their own apart from the data" (Merriam, 1998, p. 181). The categories and their associated properties reduce the data set to a more manageable size. Once the researcher is satisfied the set of categories is complete ("saturated"), it is time to flesh them out and make them more robust "by searching through the data for more and better units of relevant information" (Merriam, 1998, p. 185). The process of "axial coding" also begins, if it has not been on-going (Strauss and Corbin, 1990). In open coding, the data are taken apart, in a reductionist manner, and analyzed in detail to identify categories. In axial coding, the data are put back together in new ways to make connections between a category and its subcategories (Strauss and Corbin, 1990). Although open and axial coding are distinct procedures, the researcher often begins axial coding while still in the process of open coding (Strauss and Corbin, 1990).

In axial coding, a single category is identified as the central phenomenon of interest. The researcher then engages in the following steps (Creswell, 1998; Strauss and Corbin, 1990):

a) exploring the antecedent or *causal conditions* that influence and give rise to the phenomenon

b) identifying the *context* (specific set of properties) in which the phenomenon is embedded, e.g., time, location, number, etc.

c) specifying actions and interactions, or *strategies,* that address the central phenomenon, and the intervening conditions that bear upon these strategies (e.g., culture, economic status, history, etc.), and

d) delineating the outcomes or *consequences* of undertaking the strategies for this phenomenon.

The causal conditions, context, strategies, and consequences of the phenomenon are referred to as the subcategories of the category (Strauss and Corbin, 1990). Like the categories they refer to, subcategories have properties and dimensions that must be identified (Strauss and Corbin, 1990). Strauss and Corbin (1990) link the subcategories to a category in a set of relationships they call the "paradigm model," which highly simplified looks like this (p. 99):

> (A) CAUSAL CONDITIONS → (B) PHENOMENON → (C) CONTEXT → (D) INTERVENING CONDITIONS → (E) ACTION/INTERACTION STRATEGIES → (F) CONSEQUENCES.

To further explore the relationship of the category and its subcategories, the researcher must verify hypothetical relationships in the data; search for additional properties and dimensions of the category and subcategories; and look for variation in the phenomenon (Strauss and Corbin, 1990). There is a constant interplay between proposing hypotheses and checking them (another aspect of the "constant comparative method").

Grounded theory researchers also begin a third level of analysis, at some point, in an attempt to develop a model, hypotheses, or theory that explains the data (Strauss and Corbin, 1990; Merriam, 1998). This third cycle of coding is called "selective coding" (Strauss and Corbin, 1990). In essence, open coding provides the (developing) categories, axial coding identifies interconnections between the subcategories and categories, and selective coding builds the story that connects the major categories

(Creswell, 1998). The desired product is "a discursive set of theoretical propositions" about the phenomenon under study (Creswell, 1998, p. 150). (The propositions are discursive because they proceed to a conclusion through reason rather than intuition.)

Selective coding involves moving back and forth in a nonlinear fashion among five steps (Strauss and Corbin, 1990):

a) explicating the *story line*

b) relating *subsidiary categories* around the *core category*

c) relating categories at the dimensional level

d) validating those relationships against data, and

e) filling in categories that need further refinement or development.

The researcher must first commit to a single descriptive story about the central phenomenon of the study (Strauss and Corbin, 1990). While the story is descriptive, the *story line* is analytic, i.e., it is a conceptualization of the description. The central phenomenon is identified and named, becoming the *core category*. The properties and dimensions of this core category are developed, and the other categories are related to it as *subsidiary categories*. The subsidiary categories are arranged and rearranged "**in terms of the paradigm** [model] **until they seem to fit the story, and to provide an analytic version of the story**" (Strauss and Corbin, 1990, p. 127; emphases in the original). One or more hypotheses may now be derived regarding the relationships among the categories (Strauss and Corbin, 1990). These hypotheses are checked against new or old data to validate them. By grouping categories and relating them at the property and dimensions levels, the researcher derives the rudiments of a theory. The theory is laid out diagrammatically or in narrative form, and each statement "regarding the category relationships under varying contextual conditions are developed and ... validated against the data" (Strauss and Corbin, 1990, pp. 133.134). Finally, conceptual density and specificity are added to the theory by filling in any missing details.

Data Selection

The main sources of data used in this study are participant interviews. In this section, I describe how participants were selected and I discuss some characteristics of the participants. I also reviewed the published literature on scientific literacy as a way to develop, refine, test, and triangulate ideas, so I describe my method of selecting documents to review (especially for the historical context in Chapter 2) below.

Participant Selection. To begin a grounded theory study the researcher can purposefully choose sites, persons, and documents that promise to provide data for the study (Strauss and Corbin, 1990). The basic idea is that the initial gathering of data "is open to those persons, places, [and] situations that will provide the **greatest opportunity** to gather the **most relevant data** about the phenomenon under investigation" (Strauss and Corbin, 1990, p. 181; emphases in the original). Initially, I was most interested in interviewing United States science educators who are considered (or who consider themselves) "experts" on the subject of scientific literacy. By "expert," I mean people who are now or formally were engaged in research, programs, or policy generation directly related to (and with potentially widespread impact on) the goal of scientific literacy. There are a number of other stakeholders that one might investigate concerning the goal of scientific literacy (e.g., students, parents, teachers, legislators, business people, etc.), however, a "practical" consideration is that it is necessary to limit the scope of this exploratory study to manageable proportions. I believed members of the science education community, and especially scientific literacy "experts," would not only reveal the greatest amount of relevant information of any of the potential stakeholders, but also would be the main audience for the final products of this study.

To help keep the study in manageable proportions, I further delimited my focus to scientific literacy in the United States. I think comparing United States educators' views on scientific literacy with educators from other countries might be interesting (Tippins, et al., 2000), but it is simply beyond the scope of what I considered possible for my dissertation study.

I also imposed another criterion, namely, I wanted to interview my participants face-to-face at least once. The latter criterion limited participants to those I could physically access. I imposed this criterion because I wanted to try to elicit as genuine a response as possible. In a written response, the respondent has time to reflect on and change what he or she first intended on saying. As a result, they may tell me what they think they should say rather than what they really believe or feel. Of course, there is no guarantee that deception does not occur during a face-to-face encounter, but it may occur less often and be easier to detect (Kvale, 1996). However, I could not afford (monetarily) to personally meet with all my participants two or three times, so I did employ mail and e-mail to obtain answers to some follow-up questions.

While I was engaged in the initial conceptualization of this study, I was invited to attend the Second International Symposium on Scientific Literacy convened by members of the Institut für die Pëdagogik der Naturwissenschaften (IPN) at the University of Kiel (Germany) in October of 1998. Many of the Second Symposium participants also attended the First International Symposium in Kiel in September of 1996 (Gräber and Bolte, 1997). I believed that since these science educators have an international reputation for promoting and researching scientific literacy, they could be considered experts and would be likely to have strong opinions on the subject. Therefore, with the selection criteria outlined above in mind, for my initial sample I purposefully chose to interview some of the United States delegates to the Second Symposium as my initial participants.

I interviewed 4 of the delegates prior to the meeting in Germany, and I interviewed another one afterwards at a later conference. I twice scheduled interviews with another of the delegates, but complications arose and the interview never took place.

It is important for me to say here that in addition to the 5 delegates I interviewed as described above, I also interviewed two delegates that I later chose not to use as participants in this study. My primary reason for not using their interviews for data is they do not fit my definition of 'university science educator,' and hence the views they present do not 'belong' to the group of stakeholders I have decided to study. I had already assigned these two individuals pseudonyms, and the reader will no doubt note the alphabetical gap in the participants' pseudonyms listed in Table 3.2.

Table 3.2.
Participant Pseudonyms and Characteristics
The participants are listed in the order they entered the study. Note that pseudonyms were assigned by the researcher and have no particular significance.

Pseudonym	**Gender**	**Primary Activities Related to Scientific Literacy**
Dr. Andrews	Male	Science education professor, large university
Dr. Benjamin	Male	Science education professor, small university
Dr. Curtis	Male	Science education professor, mid-sized university
Dr. Dobson	Male	Science education professor, large university
Dr. Gilbert	Female	Science education professor, large university
Dr. Howard	Male	Science education professor, large university
Dr. Infeld	Female	Science education professor, large university
Dr. Johnson	Male	Science and science education professor, large university
Dr. Kellogg	Female	Science education professor, mid-sized university

As categories are being derived and axial coding is proceeding, more interviews can be conducted. Strauss and Corbin (1990) recommend "relational and variational sampling" at this point. This means the researcher tries to locate as many differences as possible at the dimensional level in the data so that relationships between categories and subcategories can be uncovered and validated. Sampling may be purposeful and systematic, or it can be *fortuitous*, meaning that the researcher takes advantage of an unexpected encounter (Strauss and Corbin, 1990). My sixth interviewee was encountered fortuitously. At an educational conference I was attending, I met a veteran science educator and struck up a conversation. During our talk, I explained my dissertation study to him. He asked if I would like to have him participate. Although he was not necessarily noted for his views on scientific literacy in general, he was well known for his work in science education, including one particular aspect of scientific literacy. Thus, I viewed this encounter as an opportunity to ask someone not on my "list" the same sorts of questions as the earlier interviewed scientific literacy "experts" to see if the similar or different views might emerge.

During the later stages of the qualitative study, sampling should be *discriminate*, i.e., directed and deliberate (Strauss and Corbin, 1990). The researcher "chooses the sites, persons, and documents that will maximize opportunities for verifying the story line, relationships between categories, and for filling in poorly developed categories" (Strauss and Corbin, 1990, p. 187). The idea is to test each of the hypotheses against the data in as rigorous a fashion as possible. During my interviews, I asked participants to refer me to other people who might be of interest for this study. Not all the people they recommended fit my criteria (e.g., they may not have been United States university science educators), and there were more people recommended than I could afford to visit; however, I was able to interview 3 of the recommended individuals during a one-week, cross-country drive. These 3 individuals are all nationally and internationally recognized authorities in the field of science education. I viewed these 3 participants' interviews as opportunities to test emerging hypotheses, as well as to modify or generate new ideas.

I considered 9 participants sufficient for this study because little new or relevant data seem to be emerging from the latter interviews, and I believed the emerging categories were becoming "theoretically saturated" (Strauss and Corbin, 1990, p. 188). Theoretical saturation is a necessary condition of conceptual adequacy for a grounded theory (Strauss and Corbin, 1990).

To summarize, for this study I use interview data from a total of 9 participants: 5 people who attended the Second International Symposium on Scientific Literacy in Kiel, 1 person encountered fortuitously at an educational conference, and 3 others recommended by one or more of those previously interviewed. Several other people were considered for interviews, but time and money limited my ability to gain face-to-face access to them.

Participant characteristics. Some of the participants have given permission for their real names to be used. Others have asked that their names be withheld. While it would perhaps make some of the findings more credible if I revealed the names of the participants (because most are fairly well known among science educators), for consistency's sake all names given for participants in this study are pseudonyms that I assigned (Table 3.2). To protect their anonymity and confidentiality, I am somewhat restricted in what I can reveal about the participants. I interviewed 9 college and university science educators, i.e., professors whose primary teaching and research responsibilities relate to the study of teaching and learning in science. No two participants work at the same university or site, and in fact, they live in 7 different states. Six participants are male and 3 are female. The participants generally share the following characteristics: (a) 10 or more years of experience in the fields of university science or science education; (b) participation in projects and/or publications that explicitly concern scientific literacy in the United States; and (c) although most of their work is focused on the United States, they are internationally recognized for promoting the goal of scientific literacy.

I had met some of the 9 participants prior to the study, but I only knew one of them fairly well prior to the study.

Interviews

As the main source of data, I personally interviewed members of the science education community (Laugksch, 2000) to obtain some contemporary perspectives about the goal of scientific literacy. Kvale (1996) describes an interview as "a conversation that has a structure and a purpose. It goes beyond the spontaneous exchange of views as in everyday conversation, and becomes a careful questioning and listening approach with the purpose of obtaining thoroughly tested knowledge" (p. 6). Interviews may be formal and highly structured (i.e., everyone is asked the same questions in the same order), or entirely open-ended and informal (Patton, 1990). My interviews may best be described as semi-structured (Kvale, 1996). Such interviews have "a sequence of themes to be covered, as well as suggested questions. Yet at the same time there is an openness to changes of sequence and forms of questions in order to follow up the answers given and the stories told" by the participants (Kvale, 1996, p. 124). The semi-structured approach is appropriate in my study because it allowed me to follow up on points discussed by my participants during the interview, and I could adapt both the wording and the sequence of the questions to fit the individual participant and the context of the interview (Patton, 1990). However, as interviewing and data analysis proceeded, the interview questions became more focused or structured (see Appendix A). Below, I have listed the questions I used as an interview guide towards the end of the interview phase of the study:

1. Scientific literacy has been characterized as the fundamental goal of science education. Do you agree or disagree? Please explain your response.
2. Why is scientific literacy necessary or beneficial for an individual in the United States? (Or for society?)
3. Is scientific literacy an appropriate goal for science educators in developing countries? Please explain your response.

4. We often hear that scientific literacy is a necessity for everyone. But do you know of any studies that have shown how scientific literacy benefits particular individuals or groups? Please tell me something about these studies.
5. Think of someone you know who is scientifically literate. Describe the characteristics of that person that makes him or her scientifically literate.
6. How can you tell someone who is not scientifically literate apart from someone who possesses some degree of scientific literacy?
7. How can we measure or determine someone's scientific literacy?
8. Do you consider yourself to be scientifically literate? Why or why not? (How did you get this way?)
9. How or why do some individuals become more scientifically literate than others?
10. Imagine that Einstein were somehow brought back to life, being only as knowledgeable and skilled as he was in the 1950s when he died. Would you consider the new Einstein to be scientifically literate? Please explain your response.
11. In relation to the goal of scientific literacy, please give me your opinion of the *National Standards* and *Benchmarks for Science Literacy*?
12. Morris Shamos says that scientific literacy is vague and ill-defined so that anyone can put his or her own gloss on the concept. Please respond.
13. Shamos calls scientific literacy for all a myth that is impossible to achieve. How do you respond to Shamos?
14. Shamos says that members of the general public do not believe becoming scientifically literate is necessary. Please respond. If this is true, how does it affect the achievement of the goal of scientific literacy?
15. Shamos says that not only is scientific literacy not necessary, that it may even be a bad thing--e.g., it will cost too much to achieve and create more scientists than the market can bear. How do you respond?

16. Shamos says that arguments used to promote the need for scientific literacy are actually better arguments for technologic literacy. How do you respond?
17. Shamos says that the goal of scientific literacy is a front for science educators' true goal of perpetuating their own careers and keeping the science pipeline flowing. The cry of scientific illiteracy is used as a slogan to get more funds for curriculum programs and research. How do you respond?
18. What is the future of the goal of scientific literacy? How will it change (or will it change) in the future?
19. Please look back over your responses and tell me how you define scientific literacy.
20. Is there anything else you can think of that you would like to share with me about scientific literacy?

Not all participants were asked each of these questions, but most of them were asked the majority of these questions or similarly worded ones, assuming they did not bring up these issues on their own during the interview. A few months after their initial interviews, I sent the first 5 participants a written questionnaire with these questions to follow-up on some aspects emerging from the initial analysis of interview transcripts (see Appendix B). One participant answered the questions on this questionnaire in a second-face-to-face interview, and another responded in writing. I did not receive a written reply from the other 3 participants who were sent this follow-up questionnaire.

The face-to-face interviews ranged from 45 minutes to 2 hours in length. These interviews were tape-recorded, and as soon as possible I transcribed each one verbatim. Following the interview (generally when they were mailed their transcript), I asked participants if I could use their name in this dissertation and subsequent publications. I obtained permission from most of them, but I did not hear back from 1 of them, and 2 others asked that they be given pseudonyms. For consistency’s sake, all participants’ names have been withheld, and all were assigned a pseudonym by me (Table 3.2). For the most part, the pseudonyms were inspired by author's names of books on my office bookshelf. At the request of most of the participants, I "cleaned up the language" of the interview transcripts, i.e., corrected the grammar, eliminated false starts, etc.

Documents

I often used documents written by my study participants as a way of finding possible ideas to ask about in interviews, as well as for gaining insight into what the participants told me in their interviews. Historical documents supplied me with the perspective necessary to understand how the goal of science literacy originated and changed over time. In addition, more recent documents served as tests of the emerging hypotheses from a broader cross-section of science education than my small sample of 9 participants could provide. In one case, a participant gave me written responses to some interview questions, as well as supplied me with some supplementary materials. I coded this participant's documents just like an interview transcript. Document analysis therefore helped me develop, test, modify, support, and revise elements of the evolving models.

Strauss and Corbin (1990) recommend that the researcher sample documents exactly as is done with interview or observational data, meaning that at first the researcher can be open and indiscriminate, but as the analysis continues documents need to be sampled more deliberately. In my initial search for documents to help me understand the concept of scientific literacy, I mainly located relevant documents by "back-tracing" references in an article about scientific literacy that I helped to write for *The Science Teacher* (Koballa, Kemp, and Evans, 1997). By looking at the lists of references in the sources I used in that article, I discovered a number of papers relating to scientific literacy. One of my early sources, Shamos' (1995) book, *The Myth of Scientific Literacy*, was particularly helpful in this regard. Bybee's (1997) book, *Achieving scientific literacy: From purposes to practices,* and the proceedings from the First International Symposium on Scientific Literacy (Gräber and Bolte, 1997) were also treasure troves of background sources for this dissertation study. I also began to look for scientific literacy references in the contemporary literature on science education as I conducted my normal readings in the field, and by asking other people for possible references.

As the study proceeded, I began to search the literature more systematically and selectively. I conducted several electronic searches of the science education literature, and science and education literature more generally. I used key words such as "scientific literacy," "science literacy," "scientific illiteracy," and individual names, such as "Morris Shamos," to search electronic databases including the Science Citation Index, the Social Sciences Citation Index, the Arts and Humanities Citation Index, the EBSCO*host*® database, Education Abstracts, and the Dissertation Abstracts Online. More than 10,000 journals and publications were searched in this manner. However, most of these databases only cover the past 10 to 15 years. Therefore, I also searched the ERIC Clearinghouse databases, which have sources dating back to the early 1960s, and which also contain otherwise unpublished manuscripts, such as conference papers. I also searched the on-line catalogs of the libraries of The University of Georgia and the University of Louisville. Finally, I used the keywords listed above to search the World Wide Web in general, using a search engine called "MetaCrawler" (http://www.go2net.com/search.html).

The result of all these searches was the finding of many hundreds of documents as potential sources of data. Naturally, I did not locate or use all possible sources because that would have been impractical. (For example, using "science literacy" as a keyword in the UGA library catalog resulted in over 1000 hits.) Instead, I discriminated among items using several criteria. First, I considered the items in light of my overarching purpose. Specifically, I wanted items *about* scientific literacy as a broad concept or goal, i.e., those that explained, defined, described or otherwise explored the meanings and rationales for the term or goal. I eliminated from consideration documents that simply mentioned the concept, or that were about specific methods for achieving science literacy, measurements of scientific literacy, or particular aspects of science literacy in a given content area or domain. This criterion alone eliminated the majority of potential references.

Second, as I was primarily interested in scientific literacy's history in the United States, I only considered English language documents, and only those that I considered to be readily available in the United States. If the document was very limited in circulation or access, I judged it probably had had little impact on the concept of scientific literacy overall.

A third consideration was the historical impact and original contributions to the concept of scientific literacy made by a particular reference. For example, was the item simply a report (e.g., a book review or newspaper article) that did not really add anything new to the concept? Generally, only those documents that are cited in other documents about scientific literacy were used (with the exception of some the latest ones). In other words, even if a document was about scientific literacy and was widely available, I did not consider it if it had not been cited elsewhere.

And a final but important consideration was I had to be able to gain access to the documents. For example, Bybee (1997), Laugksch (2000), and others cite the "Scientific literacy papers" from Oxford, UK, but I never located a copy of these "papers" and so they are not reviewed here.

A note on methodology: In order to help visualize and compare the characteristics of views of scientific literacy as portrayed in select documents and the participants' interview transcripts, I have constructed several matrices that appear as "Tables" in this dissertation. These matrices are meant to portray a rough level of analysis, a search for whether or not a particular element was present in the author's statements. In effect, they represent a type of *qualitative* content analysis (e.g., Altheide, 1987). These matrices should not be used in a *quantitative* sense. That is, a mark in any particular cell indicates only presence/absence of an element, and not the number of times that element was stated. These tables cannot, therefore, express more than a crude level of relative strength of emphasis for any particular element or category.

Verification Procedures

Verification of findings in a grounded theory study is the responsibility of the researcher and is an active part of the research process (Strauss and Corbin, 1990). However, I did not follow the procedures outlined by Strauss and Corbin (1990) for verification or validation of findings, because it seemed to me their recommendations are based on the canons of positivistic/quantitative research. Instead, I employed the more naturalistic procedures recommended by Creswell (1998). From a review of the literature, Creswell (1998) derives eight "verification procedures" that investigators employ or recommend to enhance the "believability" or "trustworthiness" of findings in qualitative research. I will summarize each of these strategies below, in the same order as they are in Creswell (1998), but not in order of importance. Then I will discuss the procedures I employed to assure that my findings are trustworthy.

1. "*Prolonged engagement* and *persistent observation* in the field include building trust with participants, learning the culture, and checking for misinformation that stems from distortions introduced by the researcher or informants" (Creswell, 1998, p. 201).
2. "In *triangulation*, researchers make use of multiple and different sources, methods, investigators, and theories to provide corroborating evidence" (Creswell, 1998, p. 202).
3. "*Peer review* or *debriefing* provides an external check of the research process" (Creswell, 1998, p. 202).
4. "In *negative case analysis*, the researcher refines working hypotheses as the inquiry advances … in light of negative or disconfirming evidence" (Creswell, 1998, p. 202).

5. "*Clarifying researcher bias* from the outset of the study is important so that the reader understands the researcher's position and any biases or assumptions that impact the inquiry" (Creswell, 1998, p. 202).
6. "In *member checks*, the researcher solicits informants' views of the credibility of the findings and interpretations" (Creswell, 1998, p. 202).
7. "*Rich, thick description* allows the reader to make decisions regarding the transferability … because the writer describes in detail the participants or setting under study" (Creswell, 1998, p. 203).
8. "*External audits* … allow an external consultant, the auditor, to examine both the process and the product of the account, assessing their accuracy. This auditor should have no connection to the study" (Creswell, 1998, p. 203).

The first verification procedure listed, "*prolonged engagement* and *persistent observation* in the field," is primarily used by ethnographers. My study is not an ethnography; nevertheless, I am a member of the same community as those I am studying, and this study was conducted over a three year period, so in that sense I have been able to make "decisions about what is salient to the study, relevant to the purpose of the study, and of interest for focus" in the "field" (Creswell, 1998, p. 201), as it were.

I use passages from both interviews and documents as sources of data, rather than relying on a single type of information. My study is also being reviewed by a distinguished committee of university faculty. Therefore, I have used both the methods of *triangulation* and *peer review* in this study.

I have also employed *negative case analysis* by constantly reviewing and revising my hypotheses until all the cases "fit." I have continually reflected upon and *clarified my biases* from the outset of the study, and I present some of my most pertinent biases in the narrative of this dissertation (e.g., "Researcher Perspectives and Assumptions" in this Chapter). Also in the narrative, I provide *rich, thick description* through numerous and sometimes lengthy quotations from interviews or documents.

Perhaps the greatest weakness of my study lies in the need for *member checks.* To ensure that I fairly represent my interview participants' views, I have sent all of them copies of their interview transcripts, and asked them to edit their comments. Only five of the participants returned edited transcripts. Most of their editorial comments have to do with grammar and "sense-making," or with personal references that they would rather not have published. However, even though I have spoken to and even re-interviewed some participants following their initial interviews, I have not yet presented them with a full description of my analyses, interpretations, and conclusions. I do plan to send each participant an electronic copy of my dissertation study and any papers submitted for publication to solicit their comments.

In a strict sense, I have not used the external audit procedure. However, I written several papers and made presentations related to this study (Chun, Oliver, Jackson, and Kemp, 1999; Kemp, 2000a, 2000b; Koballa and Kemp, 1998; Koballa, Kemp, and Evans, 1997, 1998; Rascoe, Chun, Kemp, Jackson, Li, Oliver, and Tippins, 1999; Tippins, Oliver, Jackson, Chun, Kemp, Li, Rascoe, Nichols, and Radcliffe, 1998; Tippins, Nichols, and Kemp, 1999). I have received feedback on those presentations from a number of individuals, and their comments have helped to shape the present dissertation.

Creswell (1998) recommends that "qualitative researchers engage in at least two of [the verification procedures] in any given study" (p. 203). Thus, even though I have not fully applied all eight verification procedures in a strict sense, I believe I have more than adequately addressed the issue of trustworthiness. It is important to note that qualitative studies are so context and researcher specific, generalizing findings to a broader context is always problematic. As Patton (1990, p. 491) puts it, qualitative methods "provide perspective rather than truth, empirical assessment of local decision makers' theories of action rather than generation and verification of universal theories, and context-bound extrapolations rather than generalizations." Nevertheless, I hope that by interviewing individuals from different areas of the country, sampling documents from a 50 year period, and providing rich, thick description in the narrative, readers will be able to determine how closely their situations match the research situation, and hence can decide whether findings can be transferred.

Study Delimitations and Limitations

The scope of this study was intentionally delimited in a number of ways, some of which have been discussed previously. Other limitations of the study arise from the nature of methods employed. Below I summarize some of the main delimitations and limitations of the study.

Delimitations

One delimitation of the study is that only professional university science educators were interviewed. Other voices (e.g., scientists, teachers, administrators, politicians, representatives from businesses, students) are not heard. I believe that for the time being this delimitation is justifiable because this is an exploratory study, and I started with those people I thought were most responsible for developing and promoting the concept of scientific literacy. This intentional limitation allowed me to keep the scope of the study to manageable proportions, as well as to conduct the study in depth. The reader may note that elsewhere I have collaborated with other researchers to explore perspectives on scientific literacy from a broader array of stakeholders (e.g., Rascoe, *et al*., 1999; Tippins, *et al*., 1998).

Another delimitation is that I have interviewed all United States based educators, thus the study is United States centered. Scientific literacy, however, is a goal of science education in many countries (Laugksch, 2000), so further studies with international scope are certainly desirable. I think comparing United States educators' views on scientific literacy with educators from other countries might be interesting (e.g., Tippins, et al, 2000), but it is simply beyond the scope of what I considered possible for my dissertation study.

Limitations

Access to participants was a limitation of this study; potential participants are located throughout the country. I did have a small pool of funds for traveling, but there was no practical way to access everyone who might be considered (or who might consider themselves) experts in scientific literacy. I interviewed the majority of participants while they were attending professional conferences.

Most of my data come from one-time personal interviews. Although I attempted to follow up with written interviews, my participants did not always respond to my attempts. Because I have only met some of the participants once or twice, it is possible they told me what they thought I wanted to hear rather than what they truly think, though I did not perceive any intentional deception during the interviews or afterwards. I also hoped to relate participants' interview data with their published views; however, some of the participants did not wish to have their identities revealed, so I chose to keep all the participants' identities in confidence and I was not able to triangulate my findings to the degree I had hoped. These facts combined with the small number of participants and the general ("subjective") nature of qualitative studies means that any results or hypotheses derived herein should be viewed as tentative, and should not be construed as fully representative of the science education community as a whole. Triangulation and follow-up interviews help to guard against possible deception or misunderstandings.

One limitation of the historical part of the study is I did not analyze literature sources that do not use the term "scientific literacy" or one of its morphs, but which may well have contributed to the development of the concept. For example, I did not use sources that refer to one particular aspect of scientific literacy, such as, "intellectual independence" (Norris, 1997). Nor did I consider those documents that speak about "public understanding of science" or "science for all," unless they directly address "scientific literacy" as well. Even though these phrases are often viewed as synonyms for "scientific literacy," I did not want to make the assumption that they are, in fact, talking about the same concept. "Public understanding of science," for example, can be viewed as one aspect of scientific literacy. Additionally, "scientific literacy" can be viewed as a product, whereas "science for all" can be viewed as the means of achieving that goal. Even if both are viewed as end states, I have reason to believe that they are not the same goal, and may actually be contradictory aims (Tippins, Nichols, and Kemp, 1999; Kemp, 2000a).

Researcher Perspectives and Assumptions

Any research is influenced by the beliefs of those conducting the research (Creswell, 1998; Spector and Glass, 1991). So that the reader may understand my assumptions and perspectives better, I will attempt to make relevant ones explicit.

First, I think it is important to note that I am a goal-oriented person. I believe improvement and progress come from setting and then working towards goals. In part, this belief arose from my training as a teacher, where I learned about setting goals and objectives for my students. I have found that setting and working towards personal goals helps me improve myself as a teacher, researcher, and human being. Because it works for me, I believe goal-oriented behavior can also be important for others, such as science educators in general.

One of my main goals has been to help people learn science. Since benefits and risks resulting from the actions of scientists are a daily part of all our lives, I believe everyone deserves and needs the best possible education in the sciences. I have been a teacher for more than 15 years, at both the high school and college level. While I have had some students who loved my science classes, I have also had a number of students who did not learn what I intended for them to learn. Many of them thought they were "no good at science," and I worry that if my students are typical of other students across the United States, then there are many people who are missing out from the possible benefits of knowing, understanding, and liking science.

I often ask myself, is there something about science that makes it too difficult to learn for some people? Or are there impediments to the learning of science that can be overcome if we could only identify them? The search for answers to these questions motivated me to return to graduate school to obtain a Ph.D. in science education, where I discovered that the goal I had been striving for in my science teaching is called "scientific literacy." (I think it is significant that I was unaware of this term, even though a science teacher for many years, until I began my graduate studies.)

My readings in graduate school convinced me a lot of science education research is redundant, and goes in cycles based on popularity rather than "results." I have read statements such as those of Bybee (1997, p. 25), who says, "The last fifty years of science education reveal a pattern of cycles of reform. ... [Yet] reform had little effect on teaching and learning in classrooms. We offer a seemingly limitless supply of activities, techniques, and materials, but the cumulative effect is only marginal. We have to ask why this is so." It is my personal aim to improve the discipline of science education by addressing this question.

My initial thinking about this particular research project was heavily influenced by my reflections on Shamos' (1995) book, *The Myth of Scientific Literacy*. When I first read the book in 1997, I was intrigued by the arguments Shamos put forth. Since he was criticizing science education's central goal, I thought other science educators would quickly challenge Shamos' arguments. However, after a search of the *Social Sciences Citation Index* in March 1998, I found that there were few references to Shamos in the literature (or, at least, in the journals covered by the *Index*). From conversations with colleagues, I knew that science educators were at least somewhat aware of Shamos' book. The idea that science educators might not be concerned their explicit central goal was being criticized interested me. Was the goal of science literacy so well entrenched that no attack could harm it? Or was the goal not important enough to defend? Did science educators really care about this goal at all?

It is no doubt important to note that I am a novice university science educator studying other university science educators. This insider's view gives me some insights into my participants' ways of thinking, but also carries with it some risks. For example, I am able to understand my participants' conversations and their references because I have experience and training in the field. On the other hand, my participants may have beliefs or assumptions that I accept uncritically because I am, though unaware, also in possession of those same views. For example, I readily accepted the reasons for the desirability of scientific literacy given in the first paragraph of the *National Science Education Standards* (NRC, 1996) until I read Shamos' (1995) book. The questions of whether everyone really needed scientific literacy, or if there was any research evidence to back up this claim, simply never occurred to me prior to reading Shamos' book. I am undoubtedly still in possession of a number of biases with regards to science education as it has traditionally been enacted.

Given to the subjective nature of qualitative research, one expects to put his own voice into the mix along with the participants (Creswell, 1998). A problem I encountered during data analysis is that I have a number of "voices" competing for attention, and I was not sure if I should have been listening to one more than another. Among the voices in me are

- the novice university science educator
- the (former) high school science teacher
- the (former) scientist
- the student
- the parent
- the citizen/member of society, and
- the scientifically literate person.

For example, the high school teacher in me is looking for practical suggestions that someone can actually implement given limited time and resources and the variety of students in our classrooms. This "me" is not interested in theory, but in what works. The scientifically literate and citizen/member of society parts of me have been watching for times in which science knowledge, skills, and dispositions benefit me in daily life--so far, the number of times I actually must draw on my scientific literacy are not very numerous. This part of me questions the legitimacy of the goal of scientific literacy. I had to constantly be on my guard so the many voices did not cause me to get bogged down in competing interpretations, or overwhelm my participants' voices when it comes to drawing conclusions and implications.

Finally, I do not want to leave the reader with the impression that I think the problems faced by science educators, or educators in general, are simplistic and straightforward and will be overcome by this single research study. There are many problems faced by educators today--poverty, violence, racism, uncaring parents, budget constraints to name a few—and these issues are not going to go away just because we do more research on science education. But neither will science education make any positive changes unless educators recognize that change is necessary, know what changes need to be made, and know how to make them. By focusing on how science educators view one of the main goals of science education, namely, scientific literacy, I hope we can ultimately come to understand better how to gather our forces and focus our efforts so that progress can be made.

Audit Trail: Evolution of the Project

One interesting aspect of qualitative research in general is the methods employed and questions asked may change as the research progresses (Bogdan and Biklen, 1992). I found this to be the case in this study. Originally (April 1998), I was thinking of studying science educators' use of goals in general, or "the goal-directed nature of science education" as I called it. After further consideration, I narrowed my objectives somewhat and focused only on scientific literacy as a goal. In my prospectus for this dissertation study, approved in August 1998, I proposed to answer the following research questions and associated sub-questions:

1) What are the beliefs and attitudes of the science educators participating in this study concerning the goal of science literacy for all?

a) What do they consider to be their current definition of the goal? Has their definition changed over time?
b) How have their beliefs and attitudes about the goal influenced their present or past research and practice? For example, do they actively promote the goal and do research to further its achievement?
c) Do they believe that progress towards the goal of science literacy is being made or not? What evidence do they point to in order to support their view? Do they feel that progress is important?
d) What factors do they believe are facilitating or impeding the achievement of the goal of science literacy for all? (How do they define progress, where have they seen or not seen progress, and to what do they attribute that progress or lack thereof?)
e) What are their beliefs and attitudes towards the future of the goal? Will it, or should it, be maintained or exchanged for another goal?

2) How do the science educators participating in this study criticize and defend science literacy for all as a legitimate goal of their discipline?

a) What philosophies, rationales, and justifications do they use to criticize or defend the goal?
b) What evidence do they cite to support their view that science literacy is or is not a legitimate goal?
c) What mechanisms (e.g., writing critiques, ignoring, ridiculing) do they use to respond to others who hold a view opposite to theirs? How cognizant are they of others holding differing viewpoints?

These research questions actually have 3 distinct emphases. First, what do science educators think or believe about the goal of science literacy. Second, how do they feel about the goal? And third, how have their thoughts and feelings towards the goal influenced their actions with regard to the goal. During the course of interviewing participants, and reflecting upon those interviews, I came to believe that the three emphases outlined above are hierarchical, that is, I had to first elicit what participants thought and believed about scientific literacy before I could get at their "feelings" (attitudes/dispositions) about it. And I had to find out both their thoughts and feelings before I could say what had influenced their actions. I found that concentrating on the first of these three, i.e., their thoughts and beliefs about scientific literacy, was as much as I could do in this dissertation study. To elicit their thoughts and feelings and tie these to actions would require much more than a few relatively short interviews, and could hardly be accomplished through document analyses.

Several of my participants have been science educators for 20 or more years, and they often referred to historical events and figures during their interviews. These incidences led me to focus more attention on the history of scientific literacy than I had originally planned.

I gathered the last 3 interviews used as data in this study in May 1999. Soon after that, I left the University of Georgia and began a new job as an instructor for the Department of Secondary Education at the University of Louisville. This change in venue significantly slowed my progress in analyzing data and writing the dissertation study. Rather than being surrounded and stimulated by numerous science education researchers, I have felt relatively isolated in my new job. Time to work on the study became severely limited.

Late in 1999, I began to work on one aspect of the scientific literacy question that I have not included in this dissertation study; specifically, I explored the historical uses of the term 'scientific literacy' as an educational slogan as well as a defined term. For a year or more, I also concentrated a lot of time and attention on discerning the elements of scientific literacy in the literature in an attempt to tie together the literature with the interview data. The reader might be interested in one of the results of this investigation, a paper I presented at Year 2000 Annual Meeting of the National Association for Research in Science Teaching (Kemp, 2000b). In March 2001, I discussed the state of my dissertation with Dr. Thomas Koballa and Dr. Deborah Tippins, members of my doctoral committee. Thereafter, I made the decision—on my own—to give up my attempt to mesh the interview data and literature analysis despite having coded about 3 dozen documents spanning 1952 to 1998. I simply could not conceive of a legitimate way to knit them together seamlessly. One problem was particularly bothersome, namely, that I could not use my participants' names. My participants wrote many of the documents I was coding, so it seemed misleading to say that the literature supported someone's views when, in fact, I was using that very person's written words and they were simply being self-consistent.

After making this fateful decision, I concentrated on trying to code the interview transcripts again (for the umpteenth time) and pick out elements and rationales without referring to those constructs I had found in the literature. I felt somewhat like a prosecutor who has been instructed by the judge to ignore one line of evidence that he knows exists because it has been tainted in such a way it cannot be allowed in court. Ultimately, I believe I have been successful in deriving a tentative model of how my participants view the concept of scientific literacy, but I am painfully aware that the reader may wish I had included more evidence from the literature in the development of my model.

Summary

This interpretive research study examines the range and degree of compatibility of 9 university science educators' views on the concept of scientific literacy. In this chapter, I have summarized the philosophical and theoretical perspectives informing this study, which are derived from the interpretive research tradition in science education (Erickson, 1986; Gallagher, 1991) and the qualitative research tradition more generally (Creswell, 1998). I explain the process of constant comparative analysis (following Strauss and Corbin, 1990), which I use in this study to identify the categories, properties, and dimensions of views on the concept of 'scientific literacy.' I describe the main source of data for the study as interviews with 9 university science educators who I intentionally selected because they were identified (by self or others) as being "knowledgeable" about the subject of scientific literacy.

I interviewed each participant in person. The interviews were semi-open ended, and consisted mainly of indirect questions so that I could compare the internal consistency of their responses. For example, I asked them to describe a scientifically literate person they know; to tell why they considered themselves scientifically literate; and to decide whether or not they would consider Einstein to be scientifically literate today if he were to be resurrected somehow. I employed various verification procedures, e.g., I interviewed one person again to clarify and extend his responses, and I received written responses to questions I asked of another participant.

This chapter has also discussed major delimitations intentionally imposed on the study to keep it to manageable proportions, as well as unintentional limitations resulting from the methodology employed. It is important to note that as with any study involving a small sample size, I do not intend for the results here to be construed as fully representative of the science education community as a whole. Any hypotheses I put forth here should be viewed as tentative and limited in scope.

Finally, I have discussed some of my own perspectives and assumptions, followed by a brief history (or "audit trail") of the study so that the reader may understand my thinking better, and may also be more aware of potential biases that I am exhibiting.

In the next chapter, I will discuss the findings with regards to constructs or elements that participants' include in their views of scientific literacy.

CHAPTER 4

ELEMENTS OF SCIENTIFIC LITERACY

The purpose of this study is to examine university science educators' views on the goal of scientific literacy. A diversity of views may be hindering the pursuit of the goal. I interviewed nine university science educators in the United States, all of whom were either self-identified or identified by others as being very knowledgeable on the topic of scientific literacy. The research question being addressed in this chapter is, "How do university science educators' define and describe the concept of scientific literacy?" This question is concerned with finding the range of constructs included in the domain of scientific literacy, as well as the participants' individual views on the nature and structure of the concept. I will attempt to identify what each participant views as the essential aspects of the concept, and also constructs that the participants believe should be excluded from or viewed as separate from the province of scientific literacy.

This chapter presents a separate summary of each participant's personal views on the nature and structure of the goal of scientific literacy. Following each summary, I present a short analysis of their remarks using a framework for condensing and classifying the essence of their views that I derived during the analysis of their interview transcripts. I will explain the framework in the next section.

Later in the chapter, I examine Dimensions and elements of scientific literacy 'across' the participants in order to answer the questions, "Do university science educators have different conceptions of scientific literacy?" I will then examine the implications of the findings in the final chapter.

Framework for Classifying Elements of Scientific Literacy

As I read through the participants' transcripts, I coded them for what I called 'elements' of scientific literacy, i.e., attributes of the scientifically literate person. In the initial coding cycle, I identified a large number of potential elements, e.g., "knowledge of science concepts," "knows the history of science," "able to acquire information," "appreciates science," and so forth. Early in this initial coding cycle, I also began to look for a way to organize the elements into a more coherent and compact framework, i.e., a way to group the elements so they demonstrate themes rather than idiosyncrasies. I found that it is possible to cluster the elements into as few as three 'Dimensions,' which I designated as the 'Conceptual,' the 'Procedural,' and the 'Affective' Dimensions. The 'Conceptual Dimension' includes those things that can be classified as knowledge or understandings. The 'Procedural Dimension' covers procedures, processes, skills, and abilities that the participants think are attributes of the scientifically literate. The 'Affective Dimension' comprises a range of attributes connected to emotions, such as feelings, attitudes, values, and dispositions. From this perspective, I can now redefine an 'element' of scientific literacy to mean 'a major type of knowledge, understanding, skill, attitude, etc. that is thought to be possessed or displayed by a scientifically literate person.'

The reader may see a resemblance of the Dimensions in my frameworks to the "domains of educational objectives" outlined by Dr. Benjamin S. Bloom and colleagues (e.g., Bloom, et al., 1956; Krathwohl, et al., 1964). This resemblance is superficial. While I do cluster 'elements of scientific literacy' into groups similar to Bloom's conceptual, procedural, and affective "domains of educational objectives," I do not go further and attempt to find correspondence between the elements of scientific literacy and Bloom's objectives within each of the domains (such as knowledge, comprehension, analysis, etc.). Additionally, Bloom and his co-workers established a <u>hierarchy</u> of educational objectives within each of the three domains, i.e., some objectives require greater learning, understanding, skill, etc. than others. It is not possible—nor do I think it would serve any useful purpose at this point—to place the elements of scientific literacy within any given Dimension in any sort of hierarchy using the data derived from my interviews.

A Fourth Category?

Dispositions in the Affective Dimension can be seen as a bridge to a possible fourth dimension that would deal with the behaviors (actions, performances, and/or habits) of the scientifically literate. I hesitate to create such a dimension for the present purposes, however, because it seems not to be "conceptually congruent" with the existing categories (Merriam 1998, pp. 183). That is to say, intentional behaviors are based on knowledge, skills, and affect (Hauenstein, 1998). While knowledge, skills, and affect are undoubtedly inter-related, they are not necessarily based on one another. For example, one may find a science topic very interesting, yet have little knowledge or skill in that area. One might also know a great deal about some science topic, but that does not necessarily tell an observer how one feels about it (you might like it, hate it, or feel neutral about it). On the other hand, it does not seem reasonable to say that a person is behaving in a scientifically literate way if they do not have any knowledge of or skills in science. Any time a person acts with intent, they are more or less successful depending, in part, on what they know, are able to do, and how they feel about the action (Hauenstein, 1998). Thus behaviors seem to be in a different "class" than knowledge, skills, and affective characteristics. That is not to say that examining what scientifically literate people actually do would not be useful; it is just not the viewpoint I have adopted for this preliminary model. A fourth category is also not necessary, because as we shall see, it is possible to classify all the 'elements' for scientific literacy espoused by my participants into just 3 Dimensions.

Participants' Emphases on Dimensions of Elements

I found during my analysis of the data that most participants seem to emphasize elements from one or two Dimensions as being more important than elements of another Dimension. In broad outline, their emphases can actually be used to classify their views to a certain extent. In Table 4.1, I have outlined my interpretation of the emphasis each participant gives to the three Dimensions of scientific literacy. These interpretations are based solely on my judgment from having been immersed in this investigation; they are not based on any quantifiable method, though I will try to support my interpretation with the interview data. As the reader will note, I have subdivided the table into 4 sections, which I believe correspond to 4 different views on the emphases for scientific literacy, including: (1) a Conceptual and Affective emphasis; (2) a Conceptual and Procedural emphasis; (3) a Procedural emphasis; and (4) a Procedural and Affective emphasis.

In the next section of this chapter, I discuss the participants' views (and their emphases) in the order that they appear in Table 4.1. To present a comprehensive and flowing account of participants' views, I have reconstructed their remarks into narratives that have few of my own thoughts explicitly included. Following each narrative, I then condense and classify the essence of their views into the three Dimensions of the 'framework for classifying elements of scientific literacy.' If a participant was interviewed twice (either in person or by mail), both sets of data are discussed together. Words and phrases that seem to point to 'elements' of scientific literacy are underlined. A note on terminology: I will frequently use the terms 'endorse' or 'support' when referring to elements that were coded from participants' interview transcripts. However, to say they 'endorse' or 'support' these elements may be somewhat misleading. While I did attempt to conduct follow up interviews with participants, I did not ask them directly about my coding or classification scheme during these "member checks." In other words, I did not actually check to see if they would sanction the elements as I have coded them. Thus, I am using the terms 'endorse' and 'support' to mean 'these are the aspects of scientific literacy that I interpret as being necessary or desirable in a particular participants' view.'

Table 4.1
Advance Organizer for Chapter 4.
A comparison of the emphases given to scientific literacy Dimensions (categories of elements) among the participants. A lower case "x" indicates the participant may have given the category slightly less emphasis than another.

Participant	**Conceptual Emphasis**	**Procedural Emphasis**	**Affective Emphasis**
Johnson	X		x
Howard	X	x	
Andrews	X	X	
Kellogg	x	X	
Benjamin	x	X	
Infeld		X	
Curtis		X	
Dobson		X	
Gilbert		X	X

Conceptual (and Affective) Emphasis

Five of the participants gave a good deal of emphasis to Conceptual elements as the hallmark of scientific literacy. Put differently, they emphasize elements in the Conceptual Dimension as being of equal or greater importance than elements in the other two Dimensions. However, only one participant, Dr. Johnson, seems to put nearly all his emphasis in this Dimension. Dr. Johnson also placed a small amount of emphasis on interest in science and motivation to learn more science, hence I have dubbed his view as a "Conceptual (and Affective) Emphasis," with the parentheses designating the lesser status of the Affective elements.

Dr. Johnson's Narrative

Dr. Johnson is a faculty member at a large northeastern university, and has taught science and science education for more than 40 years. He said he agrees with Shamos' (1995) view that the concept of 'scientific literacy' is ill-defined: "it's not something that you can your finger on, and say, 'oh, here's a scientifically literate person.' But, everybody has a little bit of a different definition, and I guess we put it in different dimensions." (Note that "dimensions" was his word, and I have borrowed this term from him.) However, he says as an education construct, scientific literacy is not unusual in this regard. In education, "You don't have truths. You have consensus sometimes. A lot of time we don't, but we don't have truths." So it does not surprise him that there are different views on what 'scientific literacy' means because he does not think there is a way to establish an absolute or correct standard.

Personally, he defines 'scientific literacy' to mean that people "know about science and they can use it in their everyday lives." However, this simple statement has a lot of underlying implications. For example, Dr. Johnson said that he thinks "of scientific literacy as much broader than being knowledgeable just in one area." In fact, many "science professors [are] not scientifically literate" because they are so "specialized." As an example, he related stories about overhearing questions put to two prominent scientists who could not answer, even though he thought the questions related to their field. Furthermore, in response to my 'Einstein question,' Dr. Johnson replied:

> You asked about Einstein. I don't know, maybe in this sense he may not have been scientifically literate. I don't know how much he knew about other sciences or science in general. A lot of times people like the [prominent scientists he spoke about earlier] know their own little thing. They don't know anything else. Is that literate? I don't know. In my view, it may not be scientifically literate.

So, to him "A part of scientific literacy is awareness. It's not even necessarily depth of knowledge. It's awareness." Therefore, a scientifically literate person is "aware of the world [and] … they try to know …a little bit about everything. That's scientific literacy to me."

Even though Dr. Johnson's view embraces a "broad" knowledge of science, he does not include "technology" as a part of science or 'scientific literacy' as the *Standards* and *Benchmarks* do:

> I'm not anti-technology. I mean, no question, without this [he points at his computer] I couldn't survive. I don't think I could write anything by hand anymore. … So I think it's changed our lives. We must use technology. We must teach students to use technology. But, to me, that's the tool, that's not the scientific literacy.

He says that technology "is a great tool," and he believes that we should "teach kids how to use that tool," but it just does not fit under the rubric of 'scientific literacy' in his mind.

Dr. Johnson also had a strong opinion about scientific literacy's relation to science vocabulary:

> My view is that currently everybody's arguing that there are too many words, too much vocabulary. … I don't agree with that philosophy. … I think it's important to know vocabulary. … The bottom line in scientific literacy is that to really understand something, you've got to talk about it and you've got to be able to communicate it to somebody else. And you can't communicate unless you have words. … It's because words give you a hook to hook a concept onto. It's not that I'm against conceptual learning--that's very important obviously--but if you don't have a word, it takes you three times as long to explain the concept to somebody. If you have a word, you can immediately convey the idea and then you can talk about it.

Therefore, he concludes, "vocabulary as a means of communication about science is important."

Dr. Johnson believes one aspect of "the scientifically literate person" is that he or she "also appreciates where all this [science] is coming from, [i.e.,] appreciates the history of science." Unfortunately, he notes,

> a lot of curriculum development doesn't [include] history. There's so much information—current information—that they have to cut something out. And so history tends to go. I'd like to see a lot more put into it. … History is important. You can use it to predict the future. If we tell this to students they begin to think that history is not so bad, after all.

In his opinion, history of science is not only important to know, it is also a vehicle for teaching science. If history is incorporated properly, he says, students "get interested in it." To him, interesting students in science is vital. Only if they are interested will they be "motivated to learn more about science as they go through life." He says, "our job as teachers is to inform and to motivate students. But if we motivate students, they inform themselves… So it's this life-long learning idea."

Dr. Johnson also tries to interest his students in science by making them aware of its presence "in our culture." He does this by giving them extra credit for attending seminars and special events related to science:

> If there's a lecture somewhere on campus that's worthwhile, I encourage students to attend. I give my students … credit for going to special events. So my idea is if we give the students experiences in life, most of which relate to the sciences, they'll get interested. … If they get interested, then they can go on and become scientifically literate because once you get them excited about it, they learn it on their own.

On the other hand, "If we don't get them excited about it, they'll learn it for the semester, and then they'll forget it two weeks later."

Interesting students in science is a way of helping them to become scientifically literate, but it is also an "attitude" that is necessary for scientific literacy itself. He says that you may forget many of the specific details you learn in a given science course, but what you will remember

> is an <u>attitude</u>, a feeling about it, to be excited about it. Years later, 20 years from now when you're counting your money as a broker, you'll see an article on DNA and say, 'Wait a minute.' And all the <u>pleasant feelings</u> come back and youll want to read the article, and you can understand it. To me, this is an important component of scientific literacy. It's not what you know right now, and what you can use right now, but what you know 20 years from now.

He says that he periodically receives notes from former students "that make me believe this long-term approach works."

Dr. Johnson also believes that "part of scientific literacy is <u>maturity</u>." He sees a lot of "variation in maturity" among his college students. He remarks, "Now we can't expect 20 year old kids to be 50 years old. But some time in their life," they should come to recognize the importance of learning:

> Some kids … want to learn. …It's the ones that are the non-majors, the general public, that we're trying to make scientifically literate. For many of these students the attitude might be 'I have to take science, it's required. But I can't wait to get out of it. What I really want to do is business.' Those are the kids that I like to see later, twenty years from now. When I meet former students they don't run away. [They say,]'Hey, that was a great course.' They don't recall details of content, but they have nice feelings about it. That to me is very important, especially for the non-major. And that attitude promotes scientific literacy. If the student has a nice attitude, even though the student may be a political scientist working for the government, the student <u>liked science</u>, so the student <u>reads about science and wants to find out more</u>. They are on the way to

> scientific literacy. Others who are less mature may say, 'Thank God that's over, I passed it.' They go on to something else and wipe science out of their mind.

Therefore, "If you want scientifically literate people, you've got to think long term. You've got to think of them learning it on their own [as adults], because they want to learn it, and they're interested in it the rest of their lives. That's scientific literacy."

By his own definition, Dr. Johnson considers himself scientifically literate because he is "very interested in all sciences" and tries to keep his knowledge of science current through reading and attending lectures or presentations about science. Occasionally, he says, "I'm absolutely amazed because I don't know anything about [a particular] subject at all. And all of a sudden, I'm not literate. I don't have any depth about that subject, but I'm aware of it. And I say, 'oh, gee, I never knew that.' And so I learn something that I didn't know." He said that even though "I don't think I know everything" about science, in general "I think I'm literate in the sense that I'm aware of most of what's going on in all different fields because of things that I have experienced."

Dr. Johnson said he is aware of people who are even more scientifically literate than him, implying that scientific literacy can be viewed as a continuum. On the other hand, there seems to be a threshold level of awareness, knowledge and interest at which he considers someone to become scientifically literate. I asked him if the general public is scientifically literate, and he replied, "Oh, definitely not." He said:

> Most people that you see out there in the real world are not really scientifically literate in any sense of the word. A lot of studies have substantiated that. As I remember, one in five knew what DNA was. All the surveys have shown this dramatic lack of knowledge about science. We've got a lot of technology. … But the knowledge of science itself doesn't seem very important to people. Many people are satisfied with turning on the computer and playing computer games, and going to the science museum once in a while. But they don't seem to know a lot of science, and it's not interesting to them.

Dr. Johnson said there are a number of things that contribute to low levels of scientific literacy among the public, including changes "in the culture." For example, nowadays "everything in the culture is moving faster. Everybody expects things to be very fast and very quick." Also, "In our culture today, there's an immediacy about everything. We want to see what's happening now, what's happening tomorrow." He says people do not really care "what happened in science 20 years ago," which is why they are not more interested in the history of science. There is also an air of "lowered expectations. When I was a kid, you worried about your grades." However, today students "can get through with a 'C', which mom is very happy with now, 'Well, a C! Great!' It's not so great."

He also attributes part of the scientific illiteracy problem to programs that prepare science teachers. He is especially disappointed that most teachers of science have never really "done" any science:

> we have people in the classroom teaching students about scientific inquiry and they never did it. I think that's badly missing in the teacher preparation programs now. Teachers are teaching about science and they never did it. Somehow we should provide a research experience for science teachers. So when they teach science, they really know how it works. I think that's very important.

However, there is not enough time in the teacher preparation programs as they are currently structured to provide teachers with research experiences. Consequently, "One of the problems that we have is teachers don't know their subject well enough," and they cannot possibly help their students to become truly scientifically literate.

Finally, Dr. Johnson is skeptical of how much new standards are really going to accomplish towards the goal of scientific literacy: "It's gotten to the point that everybody thinks that new standards will solve our educational problems. I don't agree." It is not that he does not believe they are not useful. In fact, he says, "I think the *Standards* are very important. Somebody's got to say what we ought to be doing."

Even so, Dr. Johnson says that he believes standards are often used incorrectly:

> the analogy is that you don't get kids to jump higher by raising the bar. The problem is the student. So, you need to start with where students are at and work with them so they can jump higher. Then you can raise the bar a little bit. But you don't make the bar higher and then expect the kid's going to jump higher. It's sort of doing it from the wrong end.

Furthermore, many teachers do not buy into the state or national standards because oftentimes they are handed "down" as if "this is from God." Dr. Johnson says, "the most important thing is getting standards internalized, so people not only feel that it's theirs, but it's something they really believe in and want to do." This is not happening, in his view. He concludes, "The bottom line in my plan is really the teacher. That's the plan. It's that simple. Prepare teachers who are knowledgeable, caring and thoughtful, and they will develop high standards… [Then] give them the resources, and turn them loose. And kids will learn." But, he recognizes implementation of his "simple plan" would be very difficult in our current educational systems, so perhaps it is not that "simple" after all.

Dr. Johnson's Elements and Dimensions of Scientific Literacy

I coded 11 elements of scientific literacy from the analysis of Dr. Johnson's interview transcript (Figure 4.1). This is the second smallest number (only Dr. Curtis with 9 elements is smaller), but still is by no means an insignificant amount of elements to include. His view is distinct in that he emphasizes the need for a much broader awareness of science topics than the other science educators I interviewed.

Conceptual Dimension. Dr. Johnson defines scientific literacy as knowing about science and being able to use it in everyday life. He believes that the scientifically literate person is one who knows about a broad range of science topics. Scientists and professors who know a lot about one subject but little about other science disciplines are not scientifically literate in his view. He believes it is important to know the vocabulary of science so that you can communicate about it.

Conceptual Dimension of Scientific Literacy

The scientifically literate person

- possesses an awareness of a broad range of science ideas
- has a broad vocabulary of science
- is aware of the history of science
- understands scientific inquiry
- understands that science is a part of our culture

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to

- use science in their everyday lives
- understand communications about science
- communicate science to someone
- self-learn science (as an adult)

Affective Dimension of Scientific Literacy

The scientifically literate person

- is motivated to learn more about science; keeps science knowledge current
- is interested in science and finds knowing it pleasurable

Figure 4.1
An outline of Dr. Johnson's Dimensions and elements of scientific literacy

Affective Dimension. Dr. Johnson believes that science is an important part of our culture and that the scientifically literate people should be motivated to learn more about it throughout their lives. They should find it interesting, exciting even, and appreciate the history of science.

Procedural Dimension. Dr. Johnson does not place very much emphasis on elements in the Procedural Dimension, although he does note that scientifically literate people should be able to use science in their everyday lives. In order to do so, they need to be able to be capable of learning science as an adult after formal schooling. Learning science requires the ability to understand communications about science, as well as to be able to talk to others about it.

Summary of Conceptual (and Affective) Emphasis

Dr. Johnson is the only participant who put most of his emphasis on the Conceptual elements of scientific literacy. Dr. Johnson says scientific literate people "know about science and they can use it in their everyday lives." Despite the latter part of this definition, during our interview Dr. Johnson actually gave very little if any attention to providing examples of how an individual can use science for anything other than personal satisfaction. Instead, he frequently refers to scientific literacy as requiring "a broad knowledge of science," the "vocabulary of science," and being "motivated to learn more about science." In the latter regard, he does put some of his emphasis on elements in the Affective Dimension, but this emphasis is solely concentrated on the elements I call "interested in science" and "stays up to date," and does not apply to the Affective Dimension in a broader sense (hence I assign him a small "x" for the Affective Dimension in Table 4.1).

Conceptual and Procedural Dimensions Emphasis

The other four participants to emphasize knowledge and understandings of science (Conceptual elements) also emphasized skills of science (Procedural elements). Although these participants acknowledge some elements of the Affective Dimension to be important, none of them emphasize Affective elements to the same extent as they stress Conceptual and Procedural elements. Below I discuss the individual views in the order that they appear in Table 4.1, i.e., Dr. Howard is first, followed by Drs. Andrew, Kellogg, and Benjamin.

Dr. Howard's Narrative

Dr. Howard is a faculty member at a large southwestern university, and has been active in the field of science education for more than 30 years. One of the first things he wanted to make clear is that he disagrees with Shamos (1995) about the impossibility of achieving scientific literacy for all:

> Within the science education community … there's a long history that science is only for a small number of people, that only the 'able' can do [science]. And indeed if we teach physics, like many people teach physics and chemistry and such, in the old traditional way then science education for all is a myth. But [I believe] we can make the curriculum more adaptive and more responsive, rather than selective, and in that way make scientific literacy possible for all.

Dr. Howard says scientific literacy is something everyone "absolutely" needs "to be contributing citizens, to be economically self-sufficient, and aesthetically." He says that "science is part of one's tool bag," and that scientific literacy helps:

> just in terms of understanding the natural world. Kind of the aesthetic, the enjoyment out of it. Being able to understand how certain things work. But also in their own lifestyle in making choices in terms of nutrition, and choices of the household. On and on. Also in terms of their employment. Across the board.

He thinks "when you understand it, you're more comfortable with it. You can use it better. Just makes a richer life."

I asked Dr. Howard to think of a scientifically literate person he knows and to describe that person, and he replied:

> the person that comes to my mind is just very literate all the way around. He's well read. He notices what's going on. He keeps up with what's going on. He can use science in explanations. I guess the best way that I would describe him is he has a rich life. And in this rich life he pulls from all spheres of intellectual endeavor. .... He's got it together.

When I asked him more directly what his own definition of scientific literacy included, he replied, "this probably separates me from some people, … but I think you have to have knowledge of basic concepts of science--the conceptual structure of science. And I go along with what's defined in the science standards." By 'conceptual structure,' Dr. Howard says he means things "like the unifying ideas that are identified in the *National Science Standards*... [and] *Benchmarks*." Understanding the conceptual structure is important because "many of things that we learn are generative, [i.e.,] when you learn it, it takes you somewhere. I have learned some things about evolution that became generative, and they just keep adding on. … Also when you learn in mathematics to extrapolate, that becomes generative." He added that he was thinking of science more broadly than the traditional disciplines: "Scientific literacy also has to carry over into understanding technology, [as well as] the life that's around us." Later he said, "I've always argued that one of the needs for science is so that you can understand the natural world. And the same in terms of technology, that we need to understand the world that we're building."

Consistent with his view that scientific literacy means, among other things, having a knowledge of core concepts in science, Dr. Howard told me that if Einstein were brought back to life today he "probably wouldn't be scientifically literate, because he doesn't know anything about DNA … [or] a whole range of things. But he has a solid foundation [so] that he could catch up in a hurry." On the other hand, Dr. Howard noted, Einstein was so far "above the curve" in terms of intellect that "you can't put him into a normal category."

When I inquired how much science a person should know to be considered scientifically literate, Dr. Howard answered:

> That's a tough question. In *Science* magazine several years ago there's was something about a survey that indicated that most geologists didn't know anything about DNA and most biologists didn't know anything about plate tectonics. …We run into specialization. … And so I don't know that I could give you a good answer on that. I resist trying to say somebody should have so

many courses and so many hours. One or two good courses might be better for scientific literacy than 15 bummers.

Dr. Howard said that he remembers a "survey that the AAAS did back in the mid-80s where they asked scientists what constitutes scientific literacy" (see Figure 4.9). One of the main responses was a scientifically literate person is "able to read the newspaper." For example, "the *New York Times*, on Tuesday, they always run a really neat science section. And if you can pick that up and read it you'd have a good degree of scientific literacy" according to Dr. Howard. He continued, "I'm tempted to say somebody with scientific literacy could understand *Scientific American*, but that's probably pushing it too high. I'll stay with *New York Times* science section. Or be able to pick up *Time* and *Newsweek*, and if there's a section about science, to be able to understand that with a certain amount of interest."

When I inquired, Dr. Howard said that he considers himself scientifically literate. Why? Because, he says, "I read *Science* magazine. I read the *New York Times* science section. I've tried to be a life-long learner in science." Yet even though he "read[s] a lot, [and] think[s] a lot" about science he notes that he has "tremendous gaps in … knowledge." Thus, to be scientifically literate does not mean knowing the whole of science.

On the matter of vocabulary necessary to read publications such as the *New York Times*, Dr. Howard thinks educators "put too much emphasis on vocabulary" that is out of context. He says that it is his understanding that E.D. Hirsch's cultural literacy (e.g., 1987) is built around the idea that "vocabulary should come through the discourse." Similarly, he thinks "in terms of scientific literacy and how we develop it is [by] having minds rubbing against one another, rather than grinding out those vocabulary words. Conversation about matters that interest you."

So, one aspect of scientific literacy according to Dr. Howard is "it's [possession of] a body of knowledge." Another "key attribute of someone who has scientific literacy" is that they can "answer questions through observation and experimentation, rather than authority." He later added that he was primarily speaking "in terms of observing, collecting data, interpreting data" and so forth:

> And that's not just the realm of science. That goes into mathematics … [and] the things that we associate with solving problems. And again there's some debate [about] how situated that particular knowledge is. That is, if I solve a problem in science is that situated just in the science or can I transfer it over to political science or something [else]?

On the other hand, Dr. Howard noted some of the "physical skills" that we teach science students are not going to be of much use to most of them. As an example, Dr Howard said he remembers spending "a lot of time in organic chemistry calibrating thermometers." He says such things have not been useful to him and should "not" be included as part of scientific literacy.

Dr. Howard further mentioned "attitudes" as part of scientific literacy, including an understanding of "how problems are solved." He also said, "I think we would call this an attitude, [the idea] that science is tentative. That science has limitations. That it is a product--a part of--human endeavor. That we make mistakes. There's not a silver bullet—we can't wait for it to just happen—but it's a powerful tool."

Along with these general "attitudes," Dr. Howard added that the scientifically literate person is interested in science, i.e., finds it "enjoyable" and is motivated to keep up with issues and findings in science; "Otherwise, when someone finishes their formal study they're doomed [in terms of their scientific literacy] if they don't carry on some interest." The person that remains interested in science "continues to learn" about science throughout life. And so, Dr. Howard concludes, if he "was successful as a high school science teacher, tonight if there was a … *National Geographic* special on polar bears, [then] more [of his students] would turn on to watch that polar bear program than would turn over and watch a session on *Cheers*." However, he laments, "that's a pretty tough test to pass."

One final aspect of scientific literacy noted by Dr. Howard is that what is considered as 'scientifically literate' depends on the age of the person. While it was relatively easy for him to describe a scientifically literate adult that he knows, he said "I suppose if I were to take a 20 year old that I considered to be scientifically literate, that would be a bigger challenge."

Dr. Howard's Elements and Dimensions of Scientific Literacy

The elements of scientific literacy endorsed by Dr. Howard comprises a rather lengthy list—19 in all (Figure 4.2). This number is greater than those of other participants, with the exception of Dr. Dobson. Despite the high number of elements espoused by Dr. Howard, the three dimensional model of scientific literacy elements encompasses his view quite well. Dr. Howard seems to put a lot of emphasis on the Conceptual Dimension of scientific literacy, and in fact, said he thinks his emphasis on knowledge and understandings "probably separates [him] from some people." However, he also emphasized elements in the Procedural Dimension to a fair extent, and closely associates scientific literacy with literacy skills more generally.

Conceptual Dimension. In Dr. Howard's view, the scientifically literate person has command over the "basic concepts" and "conceptual structure" of science. He thinks that scientific literacy means knowing the vocabulary of science, at least to the extent that one can understand science-related articles in the popular media. The scientifically literate person should understand "technology" as well as "the natural world." They especially need to know about their own bodies and health issues so they can make healthy decisions.

Conceptual Dimension of Scientific Literacy
The scientifically literate person

- possesses a basic body of scientific knowledge
- has knowledge and understandings of the conceptual structure (unifying ideas) of science
- understands that science is a way to solve problems
- understands that science is tentative
- understands that science has limitations
- understands that science is a product of and a part of human endeavor
- understands that science relies on mathematics
- is aware of science-related issues in society
- understands relationship of science to technology

Procedural Dimension of Scientific Literacy
The scientifically literate person can

- "pull from all spheres of intellectual endeavor"; is literate in general
- read popular media accounts involving science
- converse about science matters; use science in explanations
- answer questions through observation and experimentation, including observing, collecting, and interpreting data
- apply science to personal needs (e.g., "economically")
- apply science to social needs (e.g., to be a "contributing citizen")
- self-learn more science

Affective Dimension of Scientific Literacy
The scientifically literate person

- has a "rich life"; "notices what's going on"
- is interested in science and finds it enjoyable
- stays up to date with science ideas

Figure 4.2
An outline of Dr. Howard's Dimensions and elements of scientific literacy.

Procedural Dimension. Dr. Howard closely associates scientific literacy with literacy more generally, and defines the scientifically literate person as one who could read, understand, and communicate with others about popular media accounts related to science. The other participants usually include some aspect of science communication as an element of scientific literacy, but with the exception of Dr. Infeld, they are not as explicit as Dr. Howard about associating scientific literacy with literacy more generally. (Perhaps it is so obvious to the participants that one must be language literate in order to become scientifically literate that most failed to make any mention of this more general literacy during their interviews.)

Dr. Howard emphasized that scientifically literate people can make choices and solve problems by using their scientific literacy. In fact, he thinks the scientifically literate person should be able to do science, at least to the degree that they can "answer questions through observation and experimentation, rather than authority." On the other hand, he also said that many of the "physical skills" taught in science classes (labs) are essentially useless to the average person after school.

Affective Dimension. Dr. Howard believes the scientifically literate should have some of the "attitudes" of scientists, including an "interest" in the subject so that they are constantly aware of science issues and inclined to learn more science long after they leave school. He described one scientifically literate person he knows as good at noticing "what's going on," which I am interpreting as a disposition of awareness (albeit it certainly does require the ability to observe).

Dr. Andrews Narrative

Dr. Andrews is a faculty member at a large mid-western university, and he has more than 30 years of experience as a science educator. In his view, teaching for scientific literacy now means

> helping kids be able to understand and apply [science]. [To] be able to use that knowledge in a practical sense--for more learning, for

> continuous learning. For addressing real problems. And for learning to appreciate the world around us. It's a wonderful place, you know, if you just take a look at it.

Dr. Andrews says "the emphasis on teaching for understanding and application" is something relatively new in science education. Prior to the 1990s, for example, science was "traditionally thought of as this body of knowledge which needs to be transmitted." In addition, the NSF projects of the 1960s emphasized inquiry (or "enquiry"), "and we got away from conceptual understanding, because process became important." At the other extreme, Dr. Andrews said Shamos' goals of science appreciation and awareness are "clearly … important steps." However, he says:

> I think we need to begin there, but I don't think we should end there. Because we have to recognize that our society needs people who have more than appreciation and awareness. They have to have knowledge. Everyone has to deal with their own personal health, and their own safety, and … how our human body works. That goes beyond appreciation and awareness to some level of technical understanding about it, so that we can better interpret what we're feeling, what we're seeing. What we're experiencing. What doctor's are telling us. What people on television are telling us in terms of ads, and the like. And so those are things that I think are important. And we have to think about what's going to be the appropriate level of understanding and application. What's going to be the appropriate kind of process knowledge that people need in order to be scientifically literate, to be functional citizens and workers and constructive members of our society. And to be able to live a full life, a rich life, because of their knowledge base, because of their experience, because of their understanding.

In his view, science educators must realize that simply knowing some science or knowing how science is done is not meaningful or useful for people.

In Dr. Andrews' view the "broader dimensions of science" advocated by "Project 2061 and national standards" cover most of what is now necessary for scientific literacy. By "broader dimensions" he was referring to such things as "the inquiry focus"; "the social impact focus"; and the inclusion of "history of science, technology, … [and] mathematics." He says these dimensions were not always part of the scientific literacy goal; and in fact, he attributes their current prominence to the publication of *Science for All Americans* (Rutherford and Ahlgren, 1990).

Note, however, that by "inquiry," Dr. Andrews did not mean one had to do science. One of the dimensions of scientific literacy that Dr. Andrews says the current standards and benchmarks gloss over is the ability to use existing information to find answers to personal questions:

> If you or I want to get information, we are not going to get it by empirical means. We can't. We don't have the tools, we don't have the know-how, we don't have the resources. We don't have the time. So what we're going to do is get it from somebody else's work. … A particular problem—and let's say it deals with their own health, or own diet, or own exercise, or the products we should buy, or how to solve environmental problems, or … any of the things that we would do that might have a scientific orientation—we're going to go to information that already exists, for the most part. I think almost exclusively we'll do that. So that means we have to be able to obtain, and to know how to access, information. [Getting] the information off the Internet, or out of a book, or a resource, or from a government publication, or by going and interviewing a scientist, or somebody who is knowledgeable and can add to this information—all of those require skills that need to be learned.

Obtaining information is only the first step, however. Dr. Andrews continues:

> If you get the information, there're two other things you have to do with it in order to make it useful. One is you have to be able to interpret it. You have to

> know what it means. And in order to do that, it requires a conceptual knowledge. Because you have to take these pieces of information that you get and put them into some sort of structure so that it makes sense. And so it's the sense-making process, which is a very important part of developing understanding.
>
> The second thing that you have to do is to evaluate that information. See if this information is accurate or not. All you have to do is walk up to the checkout counter at the supermarket and you see a lot of really trashy information that's never been evaluated. But a lot of people believe it. I mean if you work with eighth grade kids they'll come in and quote this stuff. We haven't created a skeptical mind. Part of the work is creating a skeptical mind. And part of it is giving enough knowledge base so that people can do this evaluation.

Once you have obtained, understood, and evaluated the information, there is still the matter of "applying this information," i.e., of "being able to use it"—"people have to be able to take other's information and use the conceptual tools to be able to evaluate it, to determine whether it's valid, useful information or not. And then learn how to apply it."

Dr. Andrews' Elements and Dimensions of Scientific Literacy

Dr. Andrews' view of scientific literacy encompasses a fairly lengthy list of elements that fall into all three Dimensions of my framework. Figure 4.3 shows my interpretation of his elements in outline form. Dr. Andrew's emphasis on understanding and application seems to imply almost equal emphasis on elements in the Conceptual and Procedural Dimensions.

Conceptual Dimension of Scientific Literacy

The scientifically literate person possesses

- knowledge and understandings of science concepts
- knowledge and understandings of the inquiry processes of science
- knowledge and understandings of the history of science
- understandings of the relationships of science to mathematics and technology
- knowledge of the applications of science
- awareness, knowledge and understandings of science in society and its social impacts

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to

- obtain, interpret, and evaluate information
- apply science practically for self (e.g., health, safety, job-related)
- apply science for social purposes (e.g., for citizenship
- solve problems with "a scientific orientation" (e.g., environmental problems)
- interpret and understand science messages in the popular media (e.g., television)
- self-learn science (after schooling)

Affective Dimension of Scientific Literacy

The scientifically literate person

- appreciates life and the world through science
- has an attitude of a skeptical mind
- appreciates science itself

Figure 4.3.
An outline of Dr. Andrews' Dimensions and elements of scientific literacy.

Conceptual Dimension. In Dr. Andrews' view, scientifically literate people have some knowledge, which contributes to their understanding of science. This knowledge includes some conceptual or content knowledge as well as some understanding of inquiry, i.e., knowledge of how science is done. In addition to what he calls the "traditional" knowledge of science, one should possess knowledge of mathematics, technology, and history of science. He also says that the scientifically literate person should be aware of the applications of science in society and its impacts.

Procedural Dimension. Dr. Andrews feels that a scientifically literate person is one who is able to apply their knowledge and understandings towards addressing personal problems and needs, such as health and safety issues, and a type of media literacy, e.g., being able to evaluate the claims of television ads. The scientifically literate person is also able to be "functional citizens and workers and constructive members of our society," which includes a degree of environmental awareness. These 'application skills' require "continuous learning," which in turn requires the abilities inquire into a problem by accessing information (e.g., using computer technology), evaluate information for validity and usefulness, and then apply the appropriate information to one's situation.

Affective Dimension. To effectively interpret and evaluate information, Dr. Andrews says the scientifically literate person should have a skeptical mind. Dr. Andrews believes scientifically literacy not only leads to an appreciation of science, but also a better appreciation of the world that helps one to "live a full life, a rich life."

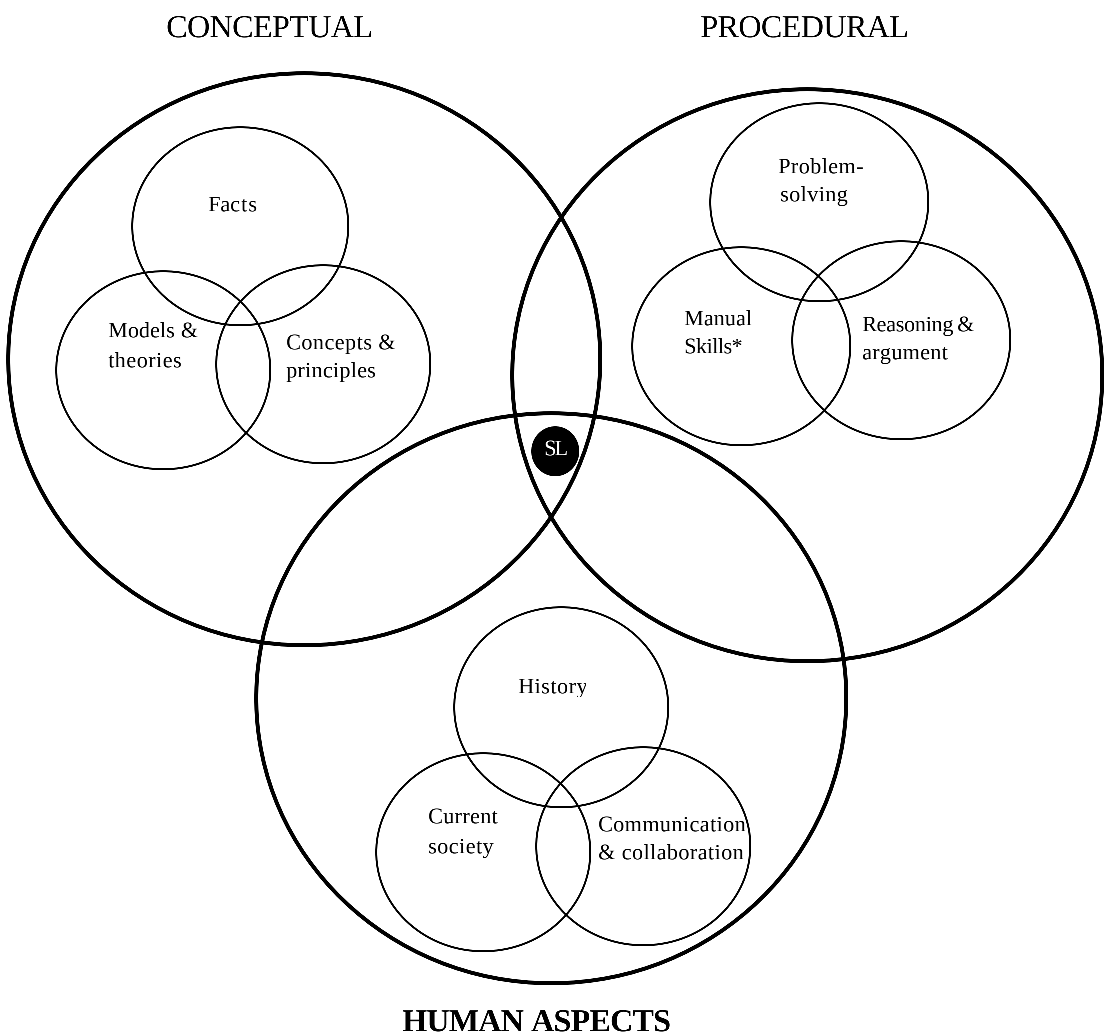
Dr. Kellogg's Narrative

Dr. Kellogg was a high school teacher for a number of years, and has worked at the university level for more than a decade. At the time of our interview (May 1999), she was on the faculty of a university in the South. Dr. Kellogg has a model of scientific literacy that she sketched and referred to throughout our interview (Figure 4.4). She says she changes the model periodically, so it is a work in progress, but she finds "it a helpful model-device for [talking about] a complex topic." She also said, "I know my philosopher friends would say it's really simplified, but that's my intention." Dr. Kellogg's model consists of a "conceptual part," a "procedural part," and a "social" or "human aspect part."

Dr. Kellogg says "the conceptual part" of her model includes "what the *Standards* call subject matter":

> I [place] three rings inside that [conceptual part]. And one of the rings is 'facts,' and I use the philosophical definition of 'fact' as something that's observable.

And then the '<u>concepts and principles</u>' [go in a second ring]. And then '<u>models and theories</u>' [go in the third ring].



* "Manual skills" include the "physical use of tools."

Figure 4.4.
<u>A representation of Dr. Kellogg's model of "science as the interaction of ideas [and] procedures, in a social context."</u>
"Where" we should be teaching to develop scientific literacy is represented by the black dot at the intersection of the three large circles.

The procedural part also has three categories:

> [One is] the 'physical use of tools,' [such as] rulers, microscopes, spectrophotometers. Then I do 'problem-solving.' And problem solving to me includes the seven processes of observe, compare, contrast, etc. And then I do 'reasoning and argument.'

And "then there's the social part[s]," which "have to do with 'history'... [and] 'change over time.' They have to do with 'communication and collaboration,' [the idea] that scientists really don't work alone. And they have to do with 'current society.'"

Dr. Kellogg says that all three "rings" are needed to produce scientifically literacy alone:

> You've got to know the ideas. Just being able to describe isn't science. Just being able to argue isn't science. And there is a reciprocal relationship between the ideas and the procedures… by which these ideas come into existence. And the ideas need to be organized around a thing called a 'model,' … science is essentially model-building, model-testing, model-revising. And that modeling is where the ideas and the procedures come together. … All of this happens in a social aspect. The fact that we choose to fund AIDS research rather than … Tourette syndrome is a political decision that influences this whole model-building thing.

Thus, scientific literacy is "the synergistic effect of when these three [rings] come together, which is the heart of this [model]."

Although she sees all three of the main "rings" as being necessary for scientific literacy, she believes that for most science educators "one or the other has taken precedence," i.e., "Each of us emphasize different parts of the model." For example, while Dr. Kellogg was always careful to include all three Dimensions of scientific literacy in her statements, she seemed to emphasize the procedural over the conceptual and social parts of her model of scientific literacy. For instance, when I asked her how scientific literacy benefits people she replied, "I think scientific literacy has a potential to benefit people primarily by giving them understanding and facility in this procedural part." She also said that if Einstein were brought back to life today, he would be scientifically literate "because he would have the capacity for the procedural. And whether it was conscious or not, he would understand the social. And although the conceptual might not be current, it would be significantly solid and able to form a foundation on which he could build." So possessing an up-to-date conceptual knowledge of science is not important if one has the "capacity for the procedural."

My impression that she emphasizes the procedural over the conceptual is further reinforced by some comments she made about the *Benchmarks* and *Standards*:

> When [Project] 2061 and the [National Academy of Science] did a comparison of the science concepts of that two documents, in the conceptual part there's a 97% overlap. And the social part, there's a large overlap, but because it's a mixture of knowing and doing, it was less easy to actually map back and forth between the two. But both of them have a human aspects component. And the still big significant difference is in the procedural. Because 2061 says that kids should know <u>about</u> problem-solving, <u>about</u> reasoning, and the *Standards* say that kids should be able to <u>do</u> problem-solving, should be able to <u>do</u> reasoning. So they say, 'know,' and we say 'know and do.' And that remains the fundamental difference in the two.

Thus, she aligns herself much more closely to the *Standards* ("we") than the *Benchmarks* ("they") because of what she sees as the *Standards'* emphasis on "the procedural." Even though she prefers the *Standards*, Dr. Kellogg said she thinks "there's too much in the conceptual box for anyone" in that document:

> I am not of the persuasion that you have to be expert in all subject matter in order to be scientifically literate. So that if you push me against the wall in physics, I'd be in real trouble. And my chemistry is old and rusty. But I think I

> understand what a fact is, what a model or concept is, and how they're structured. The nature, the purpose and structure and function of ideas. I have some idea of heuristics and problem solving methods, and reasoning and structuring argument and logic. And a very rudimentary understanding of the history of science. And how people communicate and cooperate, and what goes on in society. I think that's sort of sufficient.

Thus, she seems to emphasize the procedural aspect in comments such as these, although she always includes the other two aspects of scientific literacy, as well.

Dr. Kellogg views scientific literacy as a continuum rather than an either-or proposition:

> Although I think I am scientifically literate, I know there's an awful lot of the conceptual stuff I don't know. And I know I don't always use all the procedural stuff, and there's an awful lot of the social stuff that I know I don't know. But I don't think it's an all or nothing phenomenon.

Thus, the more science one knows, the more scientifically literate he or she is, but there is not a point above which someone is thought to be completely scientifically literate. Furthermore, once when I asked Dr. Kellogg how she would determine someone's scientific literacy, she asked me, "Is this someone of a particular age?" This rejoinder indicates that the way scientific literacy is defined may depend a person's age (or school experience level), and perhaps is not going to be defined the same way for everyone.

Dr. Kellogg thinks the concept of scientific literacy has evolved substantially over the past few decades. Whereas the conceptual aspects of science were dominant in science education in the early 1960s, by the 1970s

> the science ed community became so intrigued with the procedural [aspect of science] and was caught into some sort of reductionistic frenzy, that ultimately the procedural became separated from the conceptual part. And [it] became an end in itself, and became increasingly reductionistic. And because science is a

> complex phenomenon, the more reduced it became, the less it became recognizable to scientists as what it is that they really do. And so in the late '70s when there was a backlash against this, it was because we had lost part of the heart of the matter.

While historically there was "the tension between the ideas and the procedures," more recently the "realization that scientific model-building is a human process" has brought the social aspect of scientific literacy into greater prominence. She attributes the rise in importance of the social dimension to two "fronts":

> One is the radical shift in learning theories from behavioral to cognitive-constructivist, particularly social constructivism... And I am not a radical constructivist; I want that on the [record]. But our growing understanding that knowledge is something you do. … And you do that with other people.

The second "front" came from sociologists, such as "Bruno Latour," reporting on "all the social relationships" that go on in laboratories and other settings involving scientists (e.g., Latour and Woolgar, 1979; Latour, 1987). She says, "I think those two things opened the door to a fresh way of looking at what we do. Which doesn't necessarily mean that people weren't doing it. But I think it gave it an impact."

Thus, in Dr. Kellogg's opinion the conceptual parts of science have been "thought about … forever. The procedural part has been clear for 50, 60, 70 years. [But] The social parts of science are a relatively new idea in thinking about what it is when we're trying to do when we teach science." Because the dimensions have changed so much over time, she understands why Shamos and others think 'scientific literacy' is "vague" and "ill-defined." Furthermore, Dr. Kellogg admits "the synergy of what happens when these three components [of her model] meet is still a vague idea," and therefore she agrees "with Shamos, that we don't know how it happens." Even so, she says that she "would argue with Shamos, that … it's very possible to look at the conceptual, the procedural, and the human aspects of science" individually and see them very clearly. In a way, she says, scientific literacy "is like an art, you know it when you see it. And there aren't a whole lot of [good] examples to look at. On the other hand, I think there are elements of this vague thing that are pretty well defined."

One way I often probed for a deeper understanding of what scientific literacy means to the participants was to ask them if they considered themselves scientifically literate. To this question, Dr. Kellogg replied, "By my definition, I think I am." I asked her how she got that way. She attributed her scientific literacy to a number of things, including:

- Formal schooling (and in particular, she thanked two "good" high school teachers, two "incredible university instructors," and "a wonderful master's program")
- A personal acquaintance that she observed (her father, "who was always experimenting with how he was going to get the best possible tomatoes in his garden")
- Professional experience ("teaching, and constantly questioning what was it that I was teaching")
- Out of school experiences ("I keep myself that way by watching television, by reading")
- Personal qualities ("my curiosity about science, and my confidence in my ability to understand it, and to recognize its worth")

These latter attributes, in particular, reveal some important features of Dr. Kellogg's view of scientific literacy. For example, she seems to have acquired scientific literacy because of an "interest" in science. Indeed, she says she thinks it is important for schools and teachers to "Engage [students] in activities that they have an interest in, [which means] doing the 'golly, gee whiz' fun things with younger students and doing the satisfying puzzling things with older students." However, she says that she actually did not find science all that interesting early in her schooling—that came later. At first she was drawn in more by the "challenge" it presented:

> When you asked me about, "How did I get that way?" part of it is an incredible arrogance. As a woman I wasn't supposed to be able to do science. And that was sufficient to make me choose to do it, just because I wasn't supposed to be able to. The way it was taught and the way it was conceptualized back then, I'm not sure I would have found it inherently interesting. It became intriguing primarily because it was a challenge. And the more I've learned about science, the more I understood what it was, the more interesting it became, and it became an interest rather than a challenge. But the entrée point was not that it was interesting.

Her self-confidence remains an important aspect of her scientific literacy:

> Once upon [a] time I knew an awful lot of genetics. Recently, I have not studied genetics formally, and the field has moved. But if I chose to return to that field, I think I could bring my conceptual knowledge up to what's current. And that's part of the scientific literacy, [i.e.,] that I have the confidence to do it.

Thus, one thing that is necessary for getting people to become scientifically literate is to get them interested in science, but building up (or at least not tearing down) their confidence and self-efficacy is also a particularly important activity for schools:

> If my curiosity about science, and my confidence in my ability to understand it, and to recognize its worth hadn't happened by the time I was out of 12th grade, I probably wouldn't [have pursued] the things I did pursue.

Dr. Kellogg also views scientific literacy "as a life-long thing," not something that should be acquired and then lost after school. Scientific literacy can (and should) be maintained, for example, by watching television shows and reading about science. In fact, when I asked Dr. Kellogg about measuring scientific literacy, she answered:

> I would guess that I could determine the scientific literacy of an adult, who is not engaged in science for a source of income, by finding out what they do in

> their discretionary time. By what television they choose to watch, by the books they choose to read. By listening to their arguments about public issues that have social components. By watching, observing their reaction to news.

Later she added:

> I mean, not every book they read [would be a science book]. They've probably heard of E. O. Wilson, and they've read something by Wilson. And they may have purchased something by Gould. [Also,] by things they do. They might be nature things, they might be visits to science facilities. They might actually be high-powered hobbies that are hard to distinguish between people who do this for a living and [who do] it for a hobby.

Among such hobbies she listed "gardening," "amateur astronomy," and being a part-time volunteer "in a nature center or a museum." Thus, she described her preferred way to determine someone's scientific literacy in terms of observing their behaviors rather than by testing, as we often do in schools.

Another avenue I used to indirectly elicit participants' views on scientific literacy was to get them to talk about how progress towards the goal can be made. Dr. Kellogg believes there are a few good programs and curricular materials emerging that will help educators teach all three Dimensions of scientific literacy. Nevertheless, she believes it is the teacher who will make the biggest difference in the pursuit of scientific literacy:

> While I think that curriculum materials are necessary, I don't think they're sufficient. I believe that the necessary and sufficient condition is the teacher. And the teacher who truly understands science, the nature of science, scientific literacy, whatever this central philosophical and psychological construct is, can take average materials and create the missing components. And I think teachers who have a fact driven idea of science, and even a conceptual driven version of science, can take materials that were designed to promote scientific literacy and reduce them back to being text driven.

Dr. Kellogg believes teachers today are generally not scientifically literate "because we don't teach them to be. We teach them a lot of concepts." In other words, universities and colleges of education do not do a good job of educating teachers in the procedural and human aspects of her model. Especially in the area of the procedural, or actually learning how to do science, universities have a difficult task. Dr. Kellogg talked about one program she was aware of that she thought was moderately successful in enhancing teachers' procedural knowledge and skills. This program had teachers work in science laboratories or field settings for several weeks during the summer, and the participants also met together to discuss pedagogy and curricular issues each week. Despite its apparent success, once the grant money expired so did the interest of participating scientists, and the program ended. She sees the lack of teacher education in all three aspects of scientific literacy as a significant barrier to the achievement of the goal.

Sometimes participants spoke of ways to teach for scientific literacy that give some insight into their notions of what the concept includes. Dr. Kellogg said that one way to help promote scientific literacy would be to have "a requirement … that every student sometime during their 11th or 12th grade year engage in a capstone project. And the capstone project would engage them in inquiry." She said ideally students would

> begin with a problem about a natural phenomenon, that they need to engage in research about that problem that has to do both with laboratory research and library research. That in solving this problem they demonstrate that they have come to new understandings about an idea. And that the problem has a social consequence, either in its origin or in its implication. And that they have to do it with somebody, not by themselves. And if I were making it an assignment, … they would have to communicate with someone far away, whether it was to get information that became a source of data, or whether it was to get information about what's going on.

I asked her if she envisioned the students actually adding something original to science, but she said, "No. A new understanding for themselves. …They don't have to add to the organized body of knowledge that makes up science. But a new understanding for themselves." Therefore, she does not view the scientific literate person as someone who necessarily can conduct scientific investigations on his or her own. She concluded that her view of the capstone project is not "practical," at least "not in our current system."

Dr. Kellogg's Elements and Dimensions of Scientific Literacy

Dr. Kellogg says she thinks of scientific literacy as the synergistic effect of the intersection of three dimensions ("rings") having to do with knowledge, understandings, and skills of science; and she includes 3 'elements' in each of her dimensions (Figure 4.4). In outline form, her model includes:

Conceptual Dimension of Scientific Literacy

- Facts of science
- Models and theories of science
- Concepts and principles of science

Procedural Dimension of Scientific Literacy

- Problem solving using science skills
- Manual skills (Physical use of tools)
- Reasoning and argument

Social or Human Aspects Dimension of Scientific Literacy

- Understandings of the history of science
- Understandings of the relationships between science and society
- Understandings of communication and collaboration among scientists

Although Dr. Kellogg has a nice model of her own for the elements of scientific literacy, I believe her elements can fit even better into the framework that I have been using. For one thing, the elements listed in Dr. Kellogg's "Conceptual" and "Human Aspects" dimensions all seem to involve either knowledge or understandings about science. That is to say, they primarily deal with cognition. Therefore, it is my opinion that these two "rings" can actually be collapsed into a single dimension, the Conceptual Dimension. What is more interesting, though, is that I believe that I have identified elements of her view that she leaves out of her explicit model. In fact, as seen in Figure 4.5, I have coded 17 separate elements from my interview with Dr. Kellogg, a number that is significantly more than the 9 in her original model. However, all these elements can still be grouped into as few as three Dimensions: the Conceptual, the Procedural, and the Affective.

Conceptual Dimension of Scientific Literacy

The scientifically literate person

- Knows facts of science
- Understands models and theories of science
- Understands concepts and principles of science
- understands that science involves inquiry
- understands the history of science
- understands communication and collaboration among scientists
- understands the relationships between science and society

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to

- apply science to everyday life and to social issues
- solve problems using science skills
- use some of the tools of science (e.g., rulers, microscopes)
- reason and argue
- communicate about science
- engage in inquiry
- acquire information and to come to new understandings

Affective Dimension of Scientific Literacy

The scientifically literate person

- is interested in science
- is motivated to learn more science
- has the self-confidence to use science
- views science as worthwhile (i.e., has an appreciation of science)

Figure 4.5.
An outline of Dr. Kellogg's Dimensions and elements of scientific literacy.

Procedural Dimension. Dr. Kellogg's model includes problem solving using science skills, manual skills (physical use of tools), and reasoning and argument—abilities that clearly lie in the Procedural Dimension of both her framework and mine. Upon close analysis of Dr. Kellogg's comments, one can identify some 'elements' that she includes in scientific literacy but that seem to be left out of her explicit model. For example, in her description of the capstone project, Dr. Kellogg implied that the capacity to inquire, to acquire information and make use of it, to come to new understandings for oneself, and to apply science to personal life or social issues are abilities important for the scientifically literate person. These abilities undoubtedly fall into the "Procedural" dimension of scientific literacy in her model, but they are not clearly evident in the three categories of "problem-solving," "manual skills," and "reasoning and argument." They perhaps deserve another small "ring" or two of their own in her model (Figure 4.4). Also, although communication is implicit in "argument," it is not explicit in Dr. Kellogg's model, and it too should be added to this dimension.

Conceptual Dimension. As noted above, Dr. Kellogg's model has a "Human Aspects" ring, which contains understandings related to the history of science, relationships between science and society, and communication and collaboration among scientists. Such understanding all seem to fit into what I have termed as the "Conceptual Dimension" of scientific literacy. Similarly, the "facts, models, theories, concepts and principles of science" in Dr. Kellogg's model also clearly lie in the Conceptual Dimension. When rearranged in this way, Dr. Kellogg has a fairly large number of elements included in the Conceptual Dimension. Nevertheless, I believe that she gives slightly greater weight to the Procedural Dimension in her view of scientific literacy, as I explained in her narrative above.

Affective Dimension. Interestingly, Dr. Kellogg alluded to elements of the Affective Dimension during our interview, but she does not explicitly include this Dimension in her model for scientific literacy. For example, she says she personally became scientifically literate because she thought science was challenging in school, and she grew to find it interesting. She has a belief, a self-"confidence," that she can use science. She also says that part of her scientific literacy is recognizing the value or "worth" of science. Furthermore, she is motivated to keep up in science, and often reads books and watches televisions shows related to science. In the terminology of the field of education, these characteristics certainly fall under the rubric of the affective domain (Krathwohl, *et al*., 1964). Note that these affective traits are especially prevalent in her description of her own scientific literacy. Additionally, all the affective elements she describes here are 'positive,' i.e., they contribute to one's scientific literacy. Affective elements could also be 'negative,' i.e., prevent or take away from one's scientific literacy. For example, if a person feels science is 'evil,' then it is unlikely that person is or will become scientifically literate.

<u>Dr. Benjamin's Narrative</u>

Dr. Benjamin is a science educator at a small university in the Northeastern United States He has more than 25 years of experience in the field. Dr. Benjamin recognized the need to better define the term 'scientific literacy,' and in fact he said, "I don't think the definition of scientific literacy has ever been agreed on." At the time of our first interview he had recently attended a symposium at which the topic of scientific literacy was discussed, yet even after that conference he felt that "there's … a lot of sloppiness out there in the definition." In fact, in his view the term is used as a "slogan" that is not "too precisely defined [so that] almost anything would fit under it":

> [Scientific literacy] includes virtually everything that you could possibly imagine when it comes to scientific education--which means the principles, and concepts, and facts, and theories of the discipline, as well as the nature of scientific thought, being able to think rationally, knowing the place of science in our society, how it operates, how it relates to technology, the historical development of science--when you throw all of that in there, you've got

> something so broad that you really have no definition. It's just 'scientific literacy' is 'science education.'

On the one hand, he noted this slogan aspect of scientific literacy "is useful in that it joins us together in the pursuit of a common goal." On the other hand, "that common goal is not very specific," and therefore, it is difficult to "operationalize." He lamented, "I think this is so often what we do, and I don't want to be too critical of the field, but so often we make slogans of [educational ideas] without having that deeper philosophical basis for [them]." Dr. Benjamin included "inquiry" and "constructivism" in the same category of ideas that are more slogan-like than well grounded. He further stated:

> there are certain assumptions that underlie everything we do. We don't have many real critics in the group who are willing to say, 'You're heading down the wrong path. You don't have a real honest basis for what you're doing. You're just doing this because everyone else is doing it.' Now Morris Shamos comes along and says some of those things, and we all get very upset. But I think we should be upset more by the fact that we don't have people who are doing that--who are willing to make these kinds of claims, [i.e. that] we don't really have good reasons for doing what we're doing. And we should be moving in other directions.

Because scientific literacy has "so many different meanings, so many other things … loaded onto it," he says perhaps it is not a good idea to even use the term anymore.

Seeing as the people I interviewed for this study are very knowledgeable about scientific literacy, they often described what others conceived of as being included in the goal, while not necessarily endorsing these views themselves. For example, Dr. Benjamin asserted:

> There [are] many strong differences of opinion about scientific literacy means. For some, scientific literacy is a very broad idea. Well, for some I would say it's broad in the sense that it deals with process and a way of thinking about things,

> and the ability to explore, the ability to gather information and evidence, to investigate questions and answer them as best you can—an inquiry into the nature of something. To others, it's very specific knowledge. It's factual knowledge. And our students are scientifically illiterate to the extent that they don't know what an atom is, or a molecule is, or a germ is, or a bacterium, or something like that. To some people, that is scientific literacy. So there are vast differences within the experts in the field about what this term means. And there always have been. Someone back, … maybe even in the '60s or early '70s, like [an] NSTA statement, said that a scientifically literate person would have a working knowledge of the major fields of science: physics, chemistry, biology, and earth science. Or someone who could read with some intelligence major papers and books that were written in those fields, or something like that. So, you know, we've had lots of definitions of scientific literacy … [and] I'm not sure we've clarified it very much over the years.

An especially controversial debate according to Dr. Benjamin is the inclusion of science-technology-society (STS) topics and strategies:

> [The goal of scientific literacy] was confused right from the start. See, Paul Hurd was the first person that I've been able to identify who used the term. And Paul Hurd, of course, was somebody who right from the start jumped in against the disciplinary approach to science teaching, which is what drove the reforms of the late '50s and '60s. So, Paul Hurd's definition of scientific literacy was one that included society and technology into the picture, which is what was pulled out by the reformers who wanted to focus on the discipline. So, right from the start, that always colored the definition of scientific literacy. That it was always associated with this STS approach. There were other people who would say, 'Yes, but, we can't forget about the content itself.' And so you always had those two opposing ideas running through it, I think. And I don't

> think that's changed. I think it's still there. Because you look at today, we still do have the STS approach, … but there's also the standards. And the standards really focus much more now on specific content to be learned. So, it's both. It's the knowledge of the subject, and it's the subject in relationship to these social and technical issues that we face.

Dr. Benjamin said he thinks most science educators today are not "terribly concerned about the distinction between science and technology, … because they are so closely related." Personally, he says, "I think in many ways the distinction is artificial, and I don't think that's really something that needs to be dealt with much" in science teaching.

Dr. Benjamin sees scientific literacy somewhat differently from the views he believes others currently hold. In my first interview with him, Dr. Benjamin said

> science teaching is about getting everyone—regardless of ability or future plans—to <u>know</u> as much as they can about the world that they live in, given their various interests and abilities. [And] that we give them as much grounding in this <u>way of thinking</u> as we can. … But that regardless of your ability, both of those should be the goals of our program. Get them to know as much as they can about the <u>physical world</u> that they live in and to get them to understand this way of thinking about the world to the extent that it's possible.

I asked Dr. Benjamin if he would characterize this statement about science teaching to be his definition of the goal of scientific literacy and he replied, "Yes, I think so."

Dr. Benjamin was careful to note that he restricts "the definition of science to the physical science, our knowledge of our physical world, not the social world although we could use the term science there as well." He further added that he "would not expect that everyone would come out in the end with the same amount of knowledge" of science.

Thus, Dr. Benjamin's view of scientific literacy emphasizes knowledge about the physical world, and requires "grounding" in the scientific "<u>way of thinking</u>." Dr.

Benjamin was also careful to note this "way of thinking" also has its "limitations" and is not the only way to think:

> There is also a more poetical or intuitive way of thinking about the world that some people find to be incredibly more powerful than the scientific way of thinking about the world. The scientific way of thinking about the world is [an] analytical, 'break it down into its parts' way of thinking about the world, [and] is one way of thinking about the world that's powerful and has produced enormous outcomes, for both good and for bad.

Dr. Benjamin said the scientific "way of thinking" requires "skepticism" and the awareness of the possibility of "bias":

> The notion of bias, and in turn then, objectivity, that is, the nature of scientific thought and the potential for bias and personal agenda to come into play in the reporting of scientific claims, that's essential. Because if you're reading about and listening to people talk about scientific findings you have to have skepticism in the back of your mind. You have to be aware that the people reporting these things might have an ax to grind. I mean that's absolutely essential. If you're judging the validity of something, that is something that you have to have.

Dr. Benjamin said "objectivity and the attempt to be non-biased in their reporting," as well as the "open-mindedness that goes along with [those]" is a "value" of scientists. Dr. Benjamin said this value was perhaps the only one "that scientists have that is essential for people to know about."

When I re-interviewed him a year after our initial meeting, Dr. Benjamin said he had modified (or clarified) his views on scientific literacy somewhat, mainly in response to his reflection on some presentations on the subject at a science education research conference. He said that in addition to having knowledge of science and understanding the scientific way of thinking, a scientifically literate person is able to "take part in the conversation about science that takes place in the society that they live in," or in other words, a scientifically literate person is "somebody who can participate in discussions about scientific issues as adults." This means

> the public needs to be able to read and understand accounts that are scientifically related in the mass media. They need to be able to read the newspapers. They need to be able to read *Time* and *Newsweek* accounts. They need to be about to read the science page of the local newspaper. They need to be able to watch PBS when there's a special on some scientific investigation or some scientific controversy. And what does it take to do that? It takes an understanding of the vocabulary of science. They have to understand the concepts of science.

He continued: "You know, we say, 'well, a scientifically literate person should be a good citizen, a good decision-maker, should understand the issues of the day so that they can vote intelligently on them,' and so on. But I think something even more practical is the ability to read and understand, to communicate about science," especially when it comes to issues such as "our own health and well-being." In his view, science educators should focus on communication and "specific things like that" more "than on the kind of generalizations that we often make about what a scientifically literate person is." And what is more, he says that if you accept his view of scientific literacy, then science education is

> surprisingly more successful than we think we are. Somehow, someway, students are learning about science. … If you talk to adults, regardless of their economic background and regardless of their educational level, they seem to know--I know this goes against what many people claim to have found about this--but I think if you talk to them, you find out that they actually have learned quite a bit, somehow, about science. They have scientific knowledge. And whether that's mainly through the media or through their formal education I'm

> not sure. But somehow it's getting through to them in some way. They don't have a real precise knowledge of it. It's very difficult for them to define terms, perhaps. But it's difficult for me to define terms. But they can understand at some basic level a lot of the issues that we talk about.

Dr. Benjamin noted that while it is important to know the basic vocabulary of science, teaching too many technical or specific terms might be a barrier to achieving scientific literacy:

> I often make fun of our attempts to teach vocabulary to kids that they will never see again ever in their lives. And there's so much of that that is done. You know, like, we get into cell division in biology, and it's one thing to understand cell division and the process of cell division and the importance of the difference in meiosis and mitosis, for example--although I'm not sure even the words 'meiosis' and 'mitosis' are of much use--but when we start to get into anaphase I and anaphase II and prophase and teleophase--and this has been going on for decades and decades and decades, and continues to be taught--I just have to smile and laugh, and wonder what we're doing here.

However, he reiterates, "there are some <u>broad concepts</u> that are important to understand. The whole notion of cell division is terribly important just in understanding growth and development and understanding the formation of cancer, and so on." There appears to be a fine line between what terms need to be learned and those that are not necessary to be emphasized in school science.

As noted earlier, Dr. Benjamin believes 'scientific literacy' means that a person can "take part in the conversation about science that takes place in the society that they live in." He later clarified that he is mainly thinking about scientific literacy in terms of "an advanced, industrialized, democratic society," such as is found in the United States. Thus, one purpose for scientific literacy is to help the individual <u>participate in democracy</u>, and therefore the scientifically literate person presumably knows how science can contribute to democracy, and is able to use his or her scientific literacy when participating in democratic processes. He also described a democratic society as "a humanistic society." That is, "It's one that values persons. And it values intellect. It values rational thought. It values careful, critical thinking, and so on." Apparently, then, scientific literacy contributes to these things that are valued in a democracy. He made it clear, however, that he is more interested in promoting the benefits of scientific literacy to the individual, rather than to society at large. As he puts it, "I am not personally that interested in the political aspects of science education. … I think of it much more in terms of personal development."

One thing that Dr. Benjamin said several times is that scientific literacy is a "continuum." In other words, "people will be more or less scientifically literate or knowledgeable about science and the language of science." Dr. Benjamin felt this state was appropriate because every person participates "at a different level in the conversation about the world that they live in." He also said that he recognizes someone's scientific literacy is "dependent on their <u>interest</u>" in science, and it is important for science educators to try to get and keep them interested:

> One of the things we need to keep in mind as we create programs in science education is that we have to do it in such a way that it's appealing. So that it will be taken on by the students, and <u>continued in their own study</u>, investigation, [and] what they pay attention to in the news and the media. There's a tremendous amount of information that's available to them everyday in the newspaper and magazines and on television--and on the radio. … But if they don't care about it, if somehow they've been turned off to it, they're not going to pay attention to it. Much more happens in the rest of their lives than happens in school. What should happen in school is that they need to be presented with things in a way that it makes it palatable. I think making it palatable is absolutely essential if we're going to have any success long-term.

Clearly, in Dr. Benjamin's view, if people are not motivated to keep up with science after schooling then science educators have failed to do their job.

Dr. Benjamin thinks "having access to information" is a "useful skill." But he was careful to point out that ability to access and use information is also "a continuum":

> So that people at the upper ends are going to have the ability to access more sophisticated and technical documents than people who are the lower end of the continuum. At the lowest end you're going to have people who can perhaps pick up the newspaper and read and understand the commentary that some quote/unquote "expert" makes on the issue. Or read the letters to the editor and judge whether they're true or false, and … whether they're biased or not. …They should be able to access information. But it's enormously variable depending on their interest and their ability to do so. I wouldn't expect probably any citizen who's not a scientist to go to the *Journal of Organic Chemistry* and read the technical reports and to judge that. I think that's highly unnecessary.

Though he says some scientific skills and habits of mind are necessary for scientific literacy, Dr. Benjamin does not think that the average person necessarily needs to be able to "do science." He said, "Except for the future scientists there is no need to do science. Certainly we don't expect the adult non-scientist when faced with a question to go to that person's individual laboratory and conduct an investigation. If the community is having a problem …should the average citizen go out and conduct investigations? No, of course not." So why do we teach students how to conduct science experiments in school? Dr. Benjamin says lab exercises are primarily "a pedagogical tool for understanding the process of science. But you don't expect in the end that these people would be able to conduct their own investigations."

Dr. Benjamin's Elements and Dimensions of Scientific Literacy

As revealed in Figure 4.6, I extracted 15 separate elements of scientific literacy from the data generated by two personal interviews of Dr. Benjamin.

Conceptual Dimension of Scientific Literacy

The scientifically literate person

- has knowledge about the physical world
- has knowledge of the concepts of science
- knows vocabulary of important science concepts
- understands broad concepts (principles) of science
- understands that science has limits
- understands the relationships of science to society
- understands how science contributes to democracy

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to

- think scientifically
- decode science-related communications, i.e., to watch, listen to and read about science
- encode science communications, i.e., write, speak, or create presentations about science-related issues
- acquire information
- continue in their own study of science (after schooling)
- judge (validity of) claims by applying knowledge and values of science
- use science in everyday life (e.g., for health and well-being)
- participate in democratic processes

Affective Dimension of Scientific Literacy

The scientifically literate person

- has some of the values of scientists (e.g., objectivity and open-mindedness, and skepticism to guard against biased claims)
- is interested in science
- is inclined to continue learning science

Figure 4.6.
An outline of Dr. Benjamin's Dimensions and elements of scientific literacy.

Dr. Benjamin's statement that the "goals" of science education ought to be to get students "to know as much as they can about the physical world that they live in and to get them to understand this way of thinking about the world to the extent that it's possible" summarizes the essence of his view. Accordingly, Dr. Benjamin emphasizes elements in both the Conceptual ("to know") and Procedural ("thinking") Dimensions, although he seems to put slightly more emphasis on the latter. He views scientific literacy as a continuum, i.e., different people will be more or less scientifically literate, although he feels there is probably a minimum amount necessary to function in a democratic society.

Procedural Dimension. One of the main aspects of scientific literacy in the view of Dr. Benjamin is a "scientific way of thinking." He described such thinking as "analytical," and contrasts it with "a more poetical or intuitive way of thinking about the world" that some people find more powerful or meaningful than the scientific way of thinking. Dr. Benjamin believes a scientifically literate individual is one capable of communicating about science issues important to his or her society. (Different cultures/societies have different science-related issues.) Dr. Benjamin emphasized two aspects of science communication, as I have dubbed it. First, there is the ability to decode science information presented to—or available to—the public, e.g., in the mass media. That is to say, the individual should be able to read, listen to, or watch science-related stories in newspapers, magazines, radio, and television. Secondly, the scientifically literate person should be able to communicate with others, i.e., to write or speak (or otherwise create presentations about) about science information, or encode it. In addition, scientific literacy means being able to access and evaluate information about science and science-related issues that one becomes interested in. Everyone should be able to use science for their everyday life, including participating in democratic processes. However, scientific literacy does not include being able to "do" science, i.e., the average person does not need to conduct his or her own experiments or participate in the highly technical conversations of scientists.

Conceptual Dimension. Dr. Benjamin emphasizes that scientific literacy requires knowledge of the "physical world," which includes the "vocabulary," "concepts" and "broad" principles of science. However, Dr. Benjamin put upper limits on the level of understanding necessary for one to be scientifically literate, e.g., it is not necessary to be able to read technical journals. He also said that the scientifically literate person should know science is not the only way of thinking, i.e., that it has limits, and that people should know how science can be related to society, especially to democratic aspects of society.

Affective Dimension. According to Dr. Benjamin, "objectivity" or "open-mindedness" is essential to evaluate information. He termed this "objectivity" a "value" of science. Although he said this value was perhaps the only one "that scientists have that is essential for people to know about," I think one could make the case that "skepticism" and being aware of "the potential for bias and personal agenda to come into play" are not the same as "open-mindedness" and "objectivity," but are in fact a separate class of scientific values that he also endorses. For example, to be "objective" means to actually be non-biased, whereas to be "skeptical" means to watch for bias in others (according to Dr. Benjamin). Also, having an interest in science is a desirable trait of the scientifically literate according to Dr. Benjamin.

Summary of Conceptual and Procedural Emphasis

Four of the participants put most of their emphasis on elements of scientific literacy that I classify as belonging to the Conceptual and Procedural Dimensions. In one case (Dr. Howard), it seems that the participant gives slightly more emphasis to the Conceptual Dimension than to the Procedural Dimension. In two other cases it may be that the participants give somewhat less emphasis to Conceptual elements than to Procedural elements (Drs. Benjamin and Kellogg). And in Dr. Andrews' case, he seems to give fairly equal emphasis to both Conceptual and Procedural elements. Although all acknowledge some elements of the Affective Dimension to be important, none of them emphasize Affective elements to the same extent as they stress Conceptual and Procedural elements.

These four individuals have very broad (and diverse) views of what scientific literacy means. In the Conceptual Dimension, they particularly emphasize that to be scientifically literate means knowing science concepts, as well as understanding the broad principles of science. All four also say that it is important to know how science relates to society. Procedural elements that they emphasize the most include using science in everyday life, using science to participate in civic (democratic) processes, and being able to understand science-related stories in the popular media. To a somewhat lesser extent, these participants placed emphasis on being able to 'encode' science communications, learn science on one's own, and obtain and use information related to science issues. These four individuals do not have 'complete' agreement on Affective elements necessary for scientific literacy, although 3 did support an "interest in science" and a desire to "stay up to date" with science in the news.

Procedural Emphasis

Three participants, Drs. Curtis, Infeld, and Dobson very much emphasized Procedural elements for scientific literacy rather than Conceptual or Affective elements. All three of these individuals recognize that knowledge is important, but it is viewed as a "foundation" for reasoning (I) or a "cumulative product" (C) of learning rather than the goal, per se. Affect is also important, but perhaps more as a means for becoming scientifically literate than an actual part of the state of scientific literacy.

Dr. Infeld's Narrative

Dr. Infeld has been working at the university level in science education for about 20 years and is currently on the faculty of a large northeastern university. She has also served in other professional capacities, and taught at the high school level for several years, albeit overseas. Dr. Infeld believes "there are very few enclaves of human beings now where science-related situations aren't influential on their lives. Science and technology are sneaking in everywhere." Therefore, she says a person needs scientific literacy in order to be "a productive citizen" and to engage "in civic responsibilities." They also need it to make decisions in their "personal life," e.g., deciding whether or not to take "hormone replacement therapy." So science education in schools should provide "the kind of science that ordinary people need to be productive, good citizens and take care of the science-related parts of their daily lives."

Dr. Infeld says in her opinion scientifically literate people are those who can

> read text related to science that appears in the *New York Times,* the science section. They can read that, understand it, and maybe use it. People who can make cogent arguments about landfills, and whether there should be one placed in a certain location or community, or not. People who can use scientific information in making civic decisions. People who have enough scientific knowledge to *ask* the doctor the right questions. … Basically, that's my definition of science literacy.

In addition, she noted the need to be able to obtain information about science:

> [Scientific literacy includes] being able to get [and] to know where to get the right information. You don't have all the information that you need to know about science-related things. I don't. But I do know where to go and get information if I need it. I mean, I happen to know a lot of science, but I think it's more important to know where to get the information.

Thus, "a science literate adult" is a non-professional scientist "who knows about science and uses it in their daily life."

Dr. Infeld says she has recently re-thought "the whole notion of science literacy" because of some recent interdisciplinary experiences. She now sees it more in the context of general literacy in English and life. She says looking at science literacy in this new context is "kind of like getting out of the box."

To be scientifically literate, Dr. Infeld says she now believes

> the ability to read technical information, the ability to express technical or scientific ideas, but most of all the ability to reason are absolutely incredible. And so, that's where I'm beginning to make the link with what I've been learning from folks in English to the science part of it--because the reading, the writing, and the reasoning are true across all content areas. What's different in science or mathematics is the content, different subject matters. But it's definitely a different emphasis. It's important to know this stuff. But the emphasis on using it, I think, may be a switch in my own thinking.

She says the abilities to read, write, and reason cut across content areas, and therefore literacy in general is a more important goal for education than scientific (or mathematical) literacy, per se. She points to individuals that she knows

> who really have the ability to cut through it, whatever the topic is. And they have the ability to develop really strong arguments. [Yet they] don't know any science at all. They're highly literate on the reading and the writing and the reasoning. So, I'm not sure that the emphasis in science and math is really where it's at.

She concludes, "It may be more the literacy part rather than the science or math literacy" parts that should be receiving educators' attention.

Dr. Infeld believes there is too much emphasis on content knowledge in the *National Science Education Standards* (NRC, 1996), or as she puts it, "too much stuff!" She recalls that an early draft of the standards "focused so much on *inquiry* that the scientists who read it went crazy." Through each successive draft, more and more content got added. As a result, the *Standards* are not clear "whether the yardstick against which students' attainment should be measured is the yardstick represented by the practicing scientists, or of the science literate adult." In her opinion, using the "science literate adult" as the "yardstick" would mean considerably less content knowledge needs to be learned than is in the *Standards*. She thinks science educators would do better to consider more carefully "the quality of the arguments that people are making," rather than on whether they know "the right facts."

When I asked Dr. Infeld if Einstein would be scientifically literate today, she asked me, "Why didn't you ask me about Aristotle?" Her point was that in her view scientific literacy is mostly about the ability to reason, not about how many science facts one knows:

> I think Einstein isn't as good an example [as Aristotle] because even at the time he died, he knew an awful lot more science and had the kind of reasoning capacity that I think I was talking about. You know, this sort of ability to cut through it, the ability to put forward a cogent argument. Would he be science literate by the *National Science Education Standards* definition? Well, …there's new stuff that [has] happened. Would he know … if you asked him what he knows about plate tectonics? Pick a topic. No, he probably wouldn't know that.

So, if one emphasizes content knowledge in the definition of scientific literacy, as she thinks the *Standards* do, then "he wouldn't" be scientifically literate. But, if one uses her yardstick "he still would" be scientifically literate because she emphasizes the ability to reason. Even so, Dr. Infeld cautions:

> But, you know, I don't have to get at either end, because to do the reasoning in science, you need an incredible <u>foundation of knowledge</u>. Einstein, for example, knows something about conservation. He knows something about probability. And all of those factor in to the analysis of the situation… I think knowing stuff is important. And so, when coming down on the side of reasoning and the ability to write, I am by no means saying that knowing stuff isn't important.

In addition, she says knowing vocabulary is "pretty important," because it is primarily through words that we communicate: for example, "you [do not] get communication in science unless you have some agreement on what you mean by a 'force.'" She cautions, however, that while "vocabulary is important," the way it is traditionally taught does not promote scientific literacy, "Because it's not from the purpose of communicating. [Rather], it's in the purpose of I [the teacher] push your button on 'force,' and you give me a definition." In other words, the traditional emphasis is not on how we use words, but just on whether or not we know them for a test.

Dr. Infeld sees her "reading, writing, and reasoning" view of scientific literacy as being somewhat different from the mainstream. For example, she says that she has presented her idea of putting more emphasis on writing in science courses to teachers, with the result that "On a couple of occasions I thought I was absolutely going to get lynched. Because there are a lot of people out there who don't think that writing is a proper activity for science. And, in fact, feel that for some kids it actually puts them at risk" of falling further behind in science class. In their view, science is a class that "delivers kids from this 'link' with language, if you will" [she says these last few words between chuckles]. Personally, she thinks such teachers are doing their students a disservice. For example, she says "The tests that are being written now are being written to match the standards. The standards say that kids should be able to write extended responses." Therefore, if science students are not taught how to read the questions and write responses to them, they will not perform well on such tests.

Dr. Infeld believes people ought to "appreciate science," but in addition to seeing its "contributions," they also ought to "look for … the bad things it's got." For example, the "price tag on science research is high." She says that while the public should be aware of science, "after people become aware they come to different conclusions. … Some will say 'I'm aware of science, and I would prefer to give my support to X rather than to science.' And that's understandable and reasonable."

I asked Dr. Infeld how she became scientifically literate (after she informed me that she considers herself to be "more or less" scientifically literate). She replied,

> It started with my grandfather, who dragged me around and interestingly enough taught me about gardening, about how the stove worked, about how to fix electrical things. Now, that's Morris Shamos's theory, isn't it? The question is [since] all of the things he did with me were kind of <u>technology</u>, was that important? Or was it that I came away from those experiences believing that even as a girl I could do them?

She says she "liked science and did well in it" in school, despite the fact that "in the particular era that I grew up in … girls weren't supposed to be interested in science." When she started college and decided to major in science, she says counselors "tried to talk me out of it." She concludes that she became scientific literacy through "a combination of having a sense that I could do it, that it was okay for girls to do it, and some very good teaching along the way." Despite her own "<u>interest</u>" and "<u>sense of self-efficacy</u>" in science, she does not believe these attributes are "necessarily a part of being literate." Rather, she says, "there is a difference in the process of having become literate, and the process of being literate. I suspect there are some people who are science literate who hated science" in school. (She says this last part while laughing, perhaps downplaying this possibility somewhat.) Thus interest and self-efficacy may be more a means rather than an end.

Dr. Infeld thinks of scientific literacy as a continuum. She pointed out three factors associated with learning that contribute to the range of scientific literacy among the public. First, she observed some people become more scientifically literate than others because "they learn faster," i.e., they have a greater capacity to learn. Another factor contributing to scientific literacy is that some people are self-directed learners, i.e., "They learn in the absence of direct and good instruction." And, finally, she notes, "Some people have a greater opportunity to learn."

Dr. Infeld's Elements and Dimensions of Scientific Literacy

In absolute terms, Dr. Infeld's list of 13 elements is different from all other participants, i.e., it is not completely identical to any of the other lists (Figure 4.7). However, her list is relatively similar to Dr. Benjamin's, differing in only a few respects. This is the first time two participants have had even remotely similar lists.

Conceptual Dimension of Scientific Literacy

The scientifically literate person

- has a foundation of science knowledge
- possesses knowledge of broad principles of science
- knows some of the vocabulary of science
- understands that science is a process that relies on inquiry
- is aware of science-related issues (e.g., landfill placement)
- is aware of contributions to and problems of science in society

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to

- reason and develop arguments using science
- read and listen to popular media accounts of science (i.e., decode science communications)
- write and express science and technical ideas (i.e., encode science communications)
- use science in daily life
- obtain and use information
- use scientific information in making personal and civic decisions

Affective Dimension of Scientific Literacy

The scientifically literate person

- appreciates science (but also recognizes it sometimes has negative aspects)

Figure 4.7.
An outline of Dr. Infeld's Dimensions and elements of scientific literacv.

Both Drs. Infeld and Benjamin believe scientific literacy is largely about a way of thinking and communicating, i.e., that the Procedural Dimension of scientific literacy is more important than the other 2 Dimensions. Even so, there are significant differences between the views of these participants, especially in that Dr. Infeld says knowledge of science is just the foundation one needs for the Procedural elements of reading, writing, and reasoning in science, which she believes are the most important features of scientific literacy.

Procedural Dimension. Dr. Infeld believes the most important aspect of scientific literacy is the ability to reason, which includes the capacity to "develop … strong arguments." This element is followed closely by the abilities of reading and writing (or otherwise communicating) about science. Being able to read, write, and reason in science gives one the further abilities of being able to obtain information about science on one's own, and then make use of that information in everyday or civic situations.

Conceptual Dimension. In Dr. Infeld's view, it is important to have a foundation of science knowledge, including some understanding of the nature of science (e.g., it relies on "inquiry"). Note that in her description of Einstein's "foundation of knowledge," the examples she gives ("conservation," "probability") are not facts but broad principles of science. However, she seems to always put knowledge of both concepts and principles in the service of one's scientific abilities, specifically the abilities to read, write, and reason. For example, she says that it is important to possess some of the vocabulary of science so that one may read and write about it. Having science knowledge is not as important as being able to access and make use of information in her view. She also thinks it is important to be aware of science-related issues in society, and to understand the drawbacks of science as well as its contributions.

Affective Dimension. Dr. Infeld believes that scientific literacy provides an appreciation of science. However, the scientifically literate person does not automatically support science projects over other endeavors because he or she is aware that science has its drawbacks. She believes people are more or less scientifically literate depending on their interest and self-efficacy in science, as well as their capacity and opportunity to learn science.

Dr. Curtis's Narrative

Dr. Curtis is a science educator with more than 15 years experience at a medium-sized eastern university. Dr. Curtis believes that "there are so many different people with different opinions" that it is impossible to say with surety just what 'scientific literacy' means. Nevertheless, when I asked Dr. Curtis for his personal definition of 'scientific literacy,' he gave a succinct reply: "[Scientific literacy is a] facility with a way of thinking about the world. A way of perceiving, learning, and understanding the world. Facility with that." I then asked about the importance of content knowledge in his view, and he replied, "one of the products of seeing the world and learning about the world is knowledge." I asked him if it is the ability to acquire knowledge or the knowledge itself that makes someone scientifically literate. He explained: "If I had to have one, I'd rather have them very good at solving problems and thinking scientifically rather than having a cumulative knowledge. Because they would accumulate knowledge if they were thinking and solving problems in that manner." This statement is congruent with one he made elsewhere in the interview: "More and more people, I think, in [the past] 20 years have realized, in this long continuum of realization, that literacy is less and less an accumulation of a body of knowledge. I mean, that was true 20 years ago. But I think … [we are realizing] that science education is a way of thinking and dealing intelligently as a citizen in a culture with science issues." And later he said: "we have to change the way science is perceived. … [Once] 'science' was knowing everything that was known, that scientists had discovered .... And I think we're still caught up in some of that. And that's just slowly changing."

Dr. Curtis says he agrees with Shamos that one of the main goals for science education ought to be to promote the "appreciation" of science, but that he goes "a little too far" if he is suggesting appreciation ought to replace scientific literacy, rather than supplement it.

Dr. Curtis also commented that he feels that science educators may not really be working towards what he sees as scientific literacy:

> when you look at our textbooks that drive a lot of the curriculum, so much of the science assumes that people are going to be scientists, rather than programs that involve everyday science not in a watered-down way, like *ChemCom*. Things like that, I think, are much more the kinds of things that we should be doing than the typical chemistry text. ... And I don't think the culture of science educators has really caught up with that yet. But I think that's where we should be going, and I think we're going to be forced to go in that direction.

He thinks, "we're just trying to make everyone into scientists and being disappointed at not reaching that goal. And I think that's a mistake."

Dr. Curtis's Elements and Dimensions of Scientific Literacy

As revealed in Figure 4.8, I extracted 9 separate elements of scientific literacy from the data generated by my personal interview of Dr. Curtis. This number is smaller than the number of elements endorsed by the other participants (which range from 11 to 22 elements). The small number could be due to time constraints that caused my interview with Dr. Curtis to be relatively short (less than 45 minutes). During this short time, Dr. Curtis discussed at length several other goals or trends in science education, and his views on these subjects are generally not represented in this chapter. On the other hand, my reflections on the interview lead me to believe that Dr. Curtis's view of scientific literacy really is much more 'compact' than the other participants I interviewed.

There is little doubt that Dr. Curtis's emphasis is on elements in the Procedural Dimension of scientific literacy because of his accent on having a "facility with a way of thinking about the world." Despite the low number of elements coded from his interview, at least one falls into each of the three Dimensions of scientific literacy (Figure 4.8).

Conceptual Dimension of Scientific Literacy

The scientifically literate person possesses

- knowledge about the world
- some science content knowledge
- awareness of science issues in culture

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to

- learn science (on their own)
- think scientifically about the world
- solve problems
- deal with citizenship issues related to science
- use science in everyday life

Affective Dimension of Scientific Literacy

The scientifically literate person

- appreciates science

Figure 4.8.
An outline of Dr. Curtis's Dimensions and elements of scientific literacy.

Procedural Dimension. In Dr. Curtis's view 'scientific literacy' means facility with a way of thinking about the world and science in one's culture and everyday life that enables one to problem-solve. He very much emphasized "process" over "content" as the underlying basis for scientific literacy. That is to say, the ability to develop content understandings is more important than any specific content itself in his opinion. The scientifically literate person can use their skills in everyday life as well as to deal with "citizenship issues."

Conceptual Dimension. Scientific literacy does require some degree of knowledge about science, but in Dr. Curtis's opinion it certainly does not require a person to have a vast knowledge of science or to actually be a scientist. It also requires a certain degree of awareness about science-related issues in society (or "the culture").

Affective Dimension. One of the main goals of science education is to promote an appreciation of science, according to Dr. Curtis.

Dr. Dobson's Narrative

Dr. Dobson is a veteran of science education with more than 40 years of experience. He is a faculty member at a large mid-western university. In his interview, Dr. Dobson asserted that scientific literacy "is surely identified (by NSTA and other groups) as the major goal for science education." He said, "from my standpoint, when we're talking about a scientifically, technologically literate person, it is important that they can deal with real things which they find as important and which affect their living." Thus:

> if you say that you're able to make informed decisions, able to know where to get information, where, who to ask, what to do, [and] if you're able to act in matters of science and technology, if you're empowered to do something, it seems to me that's a fair definition ... of scientific literacy.

Similar to Dr. Curtis, Dr. Dobson says knowledge is not the most important aspect of scientific literacy. This opinion is evident when he discussed what he perceived to be the views of Morris Shamos:

> When it comes right down to his definition of scientific literacy, [Morris Shamos'] position is quite reasoned. He says that a scientifically literate person is one who can read every article in a given issue of *Scientific American* with understanding. And, he likes to boast that even he—as a physicist, as a N.Y.U. [New York University] head of a department—cannot do that. And so he says, obviously, if he can't do it, how can we expect every high school graduate or third grade student, or whatever, to be scientifically literate? Well he's taking

> the definition of scientific literacy pretty literal. If you accept his definition, he's right! But I think that NSTA and certainly AAAS and others have attempted to use the term 'scientific literacy' in a very different kind of way—of being able to do things with concepts and do things with the skills. This is the very thing that I was talking about that would be my goal and my way of assessing whether kids had learned or not.

Thus, Dr. Dobson emphasizes the ability to apply science over knowledge of science in his definition of scientific literacy.

In Dr. Dobson's view, knowledge of and skills in science are meaningless unless they are learned in context:

> [Many educators] mistakenly think that if people know these three hundred things, or E. D. Hirsch's 3001 things that they will be scientifically literate. I'm ready to say that I don't think anybody gets the tools needed for thinking by learning the concepts and skills by rote. If learning them results only in the ability to spew off the words, or perform the skills out of any context, this is a problem. The power of learning is really establishing a meaningful context to start with. Once this is established, you probably can't stop learning.

He says that the alphabet programs of the 1960s ultimately failed because they put too much emphasis on the skills of science being taught out of context:

> We said that kids could learn how to classify and how to observe better, and all the other important skills scientists' use. But nobody could ever use these skills in another context on their own. They were meaningless! Mastery of the process skills didn't do anything except provide students with a little exercise.

He later went even further and added, "I don't think anybody knows anything unless they can put a given concept or given skill in a completely new context. We ought to expect that!"

Dr. Dobson also thinks it is "important to establish what it is we're talking about both in terms of what science is and what literacy in science is." In the case of science, he says, "I don't think there's any point of having physics, geology, biology, whatever as a part of the definition," because "real research in science has become so crossed and inter-related that nobody is studying in a single discipline anymore."

Dr. Dobson was very specific that "matters of … technology" are included in his view of scientific literacy. He says that in the 1960s, there was a push towards "getting technology out of science textbooks. Technology was not science!" This idea has now completely turned around, so that "nobody today is offended by having technology included even in our *National Science Education Standards*."

Dr. Dobson endorses the Science-Technology-Society (STS) approach to teaching science because it puts science into practical and real-life contexts. In addition to teaching connections to technology, the STS approach emphasizes the social nature of science and its impacts on society. Whereas technology and science are now accepted companions in school curricula, Dr. Dobson says there is still considerable controversy over the inclusion of "society" as a part of science:

> The biggest problem with STS, among those who get upset, is that second "S." [Biologists] don't find that too offensive because society is a level of biological organization. But to the physicist—[name deleted], for example, is one of the leading critics who can almost get irate saying, "'Society!' That's not science!" [Dr. Dobson bangs his fist after each of these three words].

He continues, "People like that are only comfortable with physics, chemistry, and biology. Some of them are even a little upset with Earth Science being such a conglomeration of other 'sciences.'"

Dr. Dobson asserted his view of scientific literacy is closely aligned with that of "NSTA and … AAAS and others" who have recently defined the term. He later mailed me two lists of characteristics possessed by the scientifically literate generated by committees from these organizations (Figure 4.9, Figure 4.10). In responses to several written questions I sent after the initial interview, he often referred me to the NSTA list (Figure 4.10). For example, when I asked him to "tell me how you define scientific literacy," he replied: "I like the NSTA list!" Therefore, I will use Figure 4.10 as data while analyzing Dr. Dobson's view of scientific literacy.

Dr. Dobson believes features such as the ones listed in Figure 4.10 "if possessed and demonstrated, would give us a way of describing a scientifically literate person." However, he acknowledged that:

> most of the time such skills and abilities get us closer to what science itself is. It means wondering about the natural universe, of trying to come to grips with explanations of things that one encounters as one explores in the natural universe, and then devising some tests to see if there's any validity to the explanation. Can one collect any evidence in nature of the validity of the ideas offered? Sharing these ideas with others is another feature of science and another feature of a scientifically literate person. Again, science is a social activity that you just can't do it in a vacuum. You can say, 'that satisfies me,' or, 'that's enough evidence for me.' But if somebody else does not agree, it never becomes part of the scientific establishment. And these actions and thought processes are pretty common sorts of things. And I think even pre-school kids can perform and to think in such ways.

Thus, in contrast to Drs. Andrews' and Benjamin's views, it seems Dr. Dobson believes scientific literacy includes at least some aspects of actually being able to do science, such as "devising some tests" and collecting "evidence in nature." To further support this view, consider that Dr. Dobson said "in terms of getting students that can really experiment, really enter the world of science, who really do offer some explanations and design experiments, I think that *Standards* are on target." He is talking about going past developing students who simply "replicate the actions and the visions [of] professional scientists." He said the reforms of the 1960s had students acting like "little scientists," yet in retrospect he believes "there's all kinds of evidence that none of those programs" increased public scientific literacy because the students could not transfer their learning to other contexts and "do something with the concepts or skills on their own."

CAPABILITIES OF THE SCIENTIFICALLY LITERATE HIGH SCHOOL GRADUATE
AAAS Forum for School Science
October 1989

- Pose a question that can be addressed by the scientific method, e.g., state a hypothesis.
- Provide a scientific explanation for a natural process, e.g., photosynthesis, digestion, combustion.
- Assess the appropriateness of the methodology of an experiment.
- Read and understand articles on science in the newspaper.
- Read and interpret graphs displaying scientific information.
- Believe that scientific knowledge is worth pursuing even if it never yields practical benefits.
- Define basic scientific terms, e.g., DNA, molecule, electricity.
- Design an experiment that is a valid test of an hypothesis.
- Engage in a scientifically informed discussion of a contemporary issue, e.g., should a child with AIDS be allowed to attend public school.
- Assess the accuracy of scientific statements, e.g., the seasons change with the distance of the earth from the sun.
- Give an instance of how a scientific discovery or idea has affected society, e.g., the germ theory of disease.
- Be inclined to challenge authority on evidence that supports scientific statements.
- Describe natural phenomena, e.g., the phases of the moon.
- Apply scientific information in personal decision making, e.g., ozone depletion and the use of aerosols.
- Locate valid scientific information when needed.

Figure 4.9.
AAAS's 1989 list of "features" that characterize a scientifically literate person.
This list was given to the researcher by Dr. Dobson.

QUALITIES OF A SCIENTIFICALLY & TECHNOLOGICALLY LITERATE PERSON

NSTA Task Force Report
March 1990

- Uses concepts of science and technology and ethical values in solving everyday problems and making responsible decisions in everyday life, including work and leisure
- Engages in responsible personal and civic actions after weighing the possible consequences of alternative options
- Defends decisions and actions using rational arguments based on evidence
- Engages in science and technology for the excitement and the explanations they provide
- Displays curiosity about and appreciation for the natural and human-made world
- Applies skepticism, careful methods, logical reasoning, and creativity in investigating the observable universe
- Values scientific research and technological problem solving
- Locates, collects, analyzes, and evaluates sources of scientific and technological information and uses these sources in solving problems, making decisions, and taking actions
- Distinguishes between scientific/technological evidence and personal opinion and between reliable and unreliable information
- Remains open to new evidence and the tentativeness of scientific/technological knowledge
- Recognizes that science and technology are human endeavors
- Weighs the benefits and burdens of scientific and technological development
- Recognizes the strengths and limitations of science and technology for advancing human welfare
- Analyzes interactions among science, technology, and society
- Connects science and technology to other human endeavors, e.g., history, mathematics, the arts, and the humanities.
- Considers the political, economic, moral, and ethical aspects of science and technology as they relate to personal and global issues.
- Offers explanations of natural phenomena which may be tested for their validity.

Figure 4.10.
NSTA's 1990 list of "features" that characterize a scientifically literate person.
This list was given to the researcher by Dr. Dobson.

The lists in Figures 4.9 and 4.10 also specify qualities that might be termed 'values of science' and 'dispositions' to use one's scientific literacy. In Figure 4.10, one of the features of the scientifically literate person is "Displays curiosity about and appreciation for the natural and human-made world." Dr. Dobson also emphasized "curiosity" in my interview with him, both as a feature of scientific literacy and as a requisite for learning science:

> One of the things that I encountered at [a NARST] meeting has intrigued me. Someone was talking about how we oftentimes talk about open-ended experiences [for laboratory exercises] … But the point was that 'open-ended' leaves out critical aspects of science. The teacher or textbook or a lab outline are still in charge of defining what it is [to be learned], and all we're doing is leaving the results open. (And often these are given--making the major operation one of verification!) Really a scientifically literate person should have an 'open-entry,' i.e., should be involved in actually defining the question. The major ingredient of science is <u>curiosity</u>—often exemplified by a personal question. Without 'open-entry,' the teacher and/or textbook writers are in a very awkward position of assuming much of what science is—making students recipients or persons carrying out someone else's inquiry. I think a perfect science program would have no textbook. This could mean investigating things that represented our curiosity and <u>interests</u>, the things we wonder about. We would take every student's ideas and their explanations and try to have them check into them, have them design something, to produce the evidence of the validity of their explanation.

Thus, Dr. Dobson's view of scientific literacy certainly contains elements of the Affective Dimension, such as curiosity and interest in science.

Dr. Dobson's Elements and Dimensions of Scientific Literacy

There are 22 elements listed for Dr. Dobson's view in Figure 4.11 (if "communicate about scientific ideas" is counted as two elements, one for 'encode' and the other for 'decode').

Conceptual Dimension of Scientific Literacy

The scientifically literate person

- has knowledge of science concepts, especially in an interdisciplinary context
- understands science as a social activity
- *Understands that science and technology are human endeavors; and understands relation of science and technology to other human endeavors, e.g., history, mathematics, the arts, and the humanities*
- understands relationships between science and society
- understands relationships between science and technology
- understands relationships between science, technology, and society
- *recognizes the tentativeness of scientific/technological knowledge*
- *recognizes the strengths and limitations of science and technology for advancing human welfare*

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to

- use science in everyday life; empowered to act in matters related to science and technology
- acquire information
- make informed decisions
- devise and carry out tests of the validity of ideas and explanations; *apply skepticism, careful methods, logical reasoning, and creativity in investigating the observable universe*
- communicate about scientific ideas (i.e., encode and decode science communications)
- *engage in responsible personal and civic actions*
- *defend decisions and actions using rational arguments based on evidence*
- *distinguish between scientific/technological evidence and personal opinion and between reliable and unreliable information*

Figure 4.11.
An outline of Dr. Dobson's Dimensions and elements of scientific literacy.
See text for explanation of italics.

Affective Dimension of Scientific Literacy

The scientifically literate person

- is interested in science and nature (and *engages in science and technology for the excitement and the explanations they provide*)
- *uses ethical values to make responsible decisions; considers moral, and ethical aspects of science and technology as they relate to personal and global issues; weighs the benefits and burdens of scientific and technological development*
- *displays appreciation for the natural and human-made world*
- *values scientific research and technological problem solving*
- *remains open to new evidence*

Figure 4.11 (continued).
An outline of Dr. Dobson's Dimensions and elements of scientific literacy.
See text for explanation of italics.

I extracted 12 elements from Dr. Dobson's interview transcript, a number that is in line with other participants' views (which range from 9 to 21 elements). However, Dr. Dobson especially endorses a list of "qualities of the scientifically and technologically literate person" produced by an NSTA task force (Figure 4.10), and so I count the elements derived from Figure 4.10 as part of Dr. Dobson's view of scientific literacy. Elements in italics in Figure 4.11 are those which I derived from the lists of "qualities" of a scientifically literate person in Figure 4.10, but which Dr. Dobson did not explicitly mention during our interview. Thus, almost half (10) of the elements I attribute to Dr. Dobson were derived solely from the list in Figure 4.10.

Dr. Dobson placed most of his emphasis on elements that I categorize as part of the Procedural Dimension, such as acquiring and making use of information. To a slightly lesser extent, he emphasized affective elements such as curiosity and willingness to use science.

Procedural Dimension. Dr. Dobson stresses the abilities to acquire and use information, make informed decisions, and apply scientific literacy in practical matters.

He also said that scientifically literate people should be able to communicate with others about science. The elements he endorses for scientific literacy include several that relate to the ability to actually do science. These elements include such notions as "devising some tests to see if there's any validity to [an] explanation," and collecting "evidence in nature of the validity of the ideas offered." Figure 4.10 further states that the scientifically literate person can offer "explanations of natural phenomena which may be tested for their validity," as well as apply "skepticism, careful methods, logical reasoning, and creativity in investigating the observable universe." Although certain aspects of acting scientifically are included in the other participants' lists of elements, perhaps none go as far as Dr. Dobson in their description of the scientifically literate person.

Affective Dimension. Dr. Dobson believes that scientifically literate people are curious about nature, interested in science (and technology), and willing to use their scientific literacy. The list in Figure 4.10 further includes possession of some of the values of science and scientists (e.g., skepticism), and an appreciation of the world derived from a better understanding of it.

Conceptual Dimension. Dr. Dobson endorsed the idea that the scientifically literate person has some science content knowledge, which is a common theme among the participants. However, he was adamant that knowledge should be contextualized, i.e., that is should somehow be applicable to real life. In addition, he believes that scientific knowledge should be interdisciplinary, and in that way it would more realistically reflect real science, which he does not think is sharply divided into the traditional categories of biology, chemistry, etc. He is much more explicit and emphatic than most of the other participants about understanding the relationships between science and technology, and the relationships of these two enterprises to society. He is, he says, very "involved with STS."

Summary of Procedural Emphasis

Drs. Curtis, Infeld, and Dobson are grouped here because they emphasize elements in the Procedural Dimension more than elements in the other two Dimensions. However, the overlap in the Procedural elements they emphasize is not complete. All three say that the scientific literate person can use science in everyday life and for social/civic purposes. Dr. Infeld stresses "reasoning," Dr. Curtis accentuates "facility with a way of thinking," and Dr. Dobson emphasizes "making informed decisions"—views that seem to be reasonably close in emphasis. One importance difference between Dr. Curtis and the others is that he does not even mention elements having to do with encoding or decoding science communications. With regards to Conceptual elements, all three say that it is important to know the concepts of science, and to have some understanding of how science and society are related. Dr. Dobson goes even further and says that it is important to understand relationships between science and technology. Interestingly, Dr. Dobson places more emphasis on Affective elements than the other two. For example, he stressed "curiosity" and "interest" in science, and the list of qualities of the scientifically literate that he referred to (Figure 4.10) contains at least 5 other Affective elements. On the other hand, Drs. Infeld and Curtis endorsed only one Affective element, namely, 'appreciates science.'

Procedural and Affective Emphasis

Dr. Gilbert puts a good deal of stress on both Procedural and on Affective characteristics for scientific literacy. Like Dr. Dobson, she says she is a supporter of the STS approach to science education.

Dr. Gilbert's Narrative

Dr. Gilbert is currently on the faculty of a mid-western university and has been working at the university level for more than 10 years. Dr. Gilbert said that a scientifically literate person on the outside "would look like you and me."

> They're the person on the street. They're the janitor, or the temp' in the office. … Many of them probably would not be able to have the vocabulary that certain of us would have about talking about various issues. But, to put it in maybe a very concrete example/format, [they] would at least have an understanding that would be at a newspaper level understanding of science and the applications of science.

Like many science educators, she was a public school teacher earlier in her career. She reminisced that "public understanding of science" (her term for 'scientific literacy') has "always been a very strong interest of mine." In fact, she says, "it's always been a part of what I was trying to do as an educator." She says after teaching for a couple of years, she realized that many of her students did not really understand or like science:

> It's not that I wanted to turn them into scientists. I don't think that's appropriate as a goal. But by the same token [they] should have an appreciation for what science is, and the applications in the everyday world.

She discovered the STS approach to teaching, and "wound up doing … a lot of things that were not part of the typical science instruction at the time." She reports that she consequently observed a "tremendous response" in her students, and that the role-playing and simulations she used in her instruction became "very, very powerful learning experience[s]." Through the STS approach, she found that she could make her curricula applicable to real-life in an "inquiry-based" setting, and still "cover" the traditional concepts.

She does not particularly like the term 'scientific literacy' because she thinks it is misleading. In her mind, the goal science educators call 'scientific literacy' is broader than learning to read and write, which is what 'literacy' often connotes: "The literacy piece leaves out the decision-making piece," for example. She says science educators ought to be concerned with a "whole range [of goals] from awareness to action" related to science issues. Unfortunately, from what she's seen in the science education literature, “most people are defining [‘scientific literacy’] very narrowly as the ability to understand scientific terms like in the newspaper, or things like that, and they leave that action piece out, or it’s just kind of mentioned in passing. And they don’t really attend to it.” It is not the elements that are included in ‘literacy’ that she objects to, but “the more worthy elements” that term excludes.

Dr. Gilbert emphasized that scientifically literate people not only have the knowledge and skills needed to apply science in their lives, but they are also “aware” of science issues and inclined to “action.” However, she went on to describe how many people in the United States do not participate in public debate about science issues, either because they do not understand or do not care about what they read or hear in the public media. For example, she knows of one proposed agricultural biotechnology project being carried out by a large corporation that is being virtually ignored by the public here in the United States. She says she wonders what does “the farmer who lives 30 miles away [from the company] really think about in terms of science and how this [project] is possibly going to affect what’s going on here?’ Why is there no longer a national dialogue on these kinds of issues? Or a local dialogue? Why is the assumption in the United States made by a lot of people, ‘well, science and technology are great. We don’t have to think about it’?” In Europe, by way of contrast, some people have a much greater awareness and they are also “burning fields that have [the company’s] plants in them, because they’re protesting this whole notion of genetic engineering and biotechnology.” Thus, she describes a scientifically literate person as one who acts on science-related issues in their “daily lives,” as well as being concerned about “what goes on a local, state, national, regional, [and] global level” related to science and technology.

When I asked her if scientifically literate people have to “know how to do science,” she replied:

> I don’t think so. … They wouldn’t have to know how to do science, per se, other than in a very general [way]: ‘Scientific research? It does involve usually

> laboratory tests and [such] things.' To be honest with you, I think that level of understanding would be sufficient. Now, what really concerns me though is not only do they have to understand that laboratory testing, for example, is part of the FDA or something like that, but what are the <u>limitations</u> about some of the data you get as a result of that, and the <u>interpretation</u> of those data? That's the key piece that I see as being central to this issue of 'do I have <u>information'</u>? It's really looking at information, and what does that information represent, where does it come from, and how does it influence me and do I need to be concerned about it, or how is that information interpreted in my [situation]?

She later added:

> Do we really--do I personally need to know everything there is to know about light-bulbs and how they function--you know, electricity, electrons--in order to put a light-bulb in and have it work? No, I really don't. We have specialists in our society whose task is related to that. An electrician does have to know the science behind it. But I can be perfectly ignorant, really, about that as long as I know some basics, maybe. I flip the switch [to turn it] on, and [do] not touch it with something wet; [there are] certain life skills that you don't want to give up. But beyond that, there are some issues that I really question, does a person really need to know those?

To Dr. Gilbert, then, it is not important for most individuals to possess a deep knowledge of science, but rather a person should have the ability to ask for and use information provided by experts.

One final point Dr. Gilbert raised about scientific literacy is that it is adults—not children—who need to be aware of, and take action with regards to, science in their lives. She says,

> we tend to talk about scientific literacy as related to the K-12 population, or K-16. That's nonsense, because what influences children more than anything are

> their parents or guardians, or an adult role-model. ... And so you can't really consider it just the 'scientific literacy' of the student population without considering the parents and the larger society.

Thus, the current focus on the student population may be doing little to increase the public's scientific literacy because "an adult's need to know about this public understanding of science would probably be very different from a student in a formal educational institution."

Dr. Gilbert's Elements and Dimensions of Scientific Literacy

Dr. Gilbert endorses 13 elements of scientific literacy by my count (Figure 4.12). The proposed framework consisting of 3 Dimensions for scientific literacy works very well in Dr. Gilbert's case. No new dimensions are required to accommodate the elements she endorses. Dr. Gilbert places a great deal of emphasis on elements in the Procedural Dimension, such as acquiring information, making decisions, and communicating about science. However, she also places a lot of emphasis on the Affective Dimension, especially in the sense that a scientifically literate person should be inclined "to action" (a disposition). She focuses the least amount of attention on knowing science, i.e., the Cognitive Dimension.

Procedural Dimension. Dr. Gilbert believes it is more important for an individual to have the ability to acquire and use information when it is needed than to have a lot of knowledge stored in one's head. She says the scientifically literate person can understand popular media accounts of science, and if 'scientific literacy' is associated with literacy more generally then the person can also write about science. Perhaps most importantly, the scientifically literate person can make decisions using science, and apply their scientific literacy to everyday life and social issues.

Affective Dimension. Dr. Gilbert says scientifically literate people actively seek out opportunities to use their scientific literacy, especially in matters related to social issues. This means participating in the "dialogue" about science- and technology-related issues in society, and being inclined to act on ones convictions. Dr. Gilbert also believes the scientifically literate person has some appreciation for science, e.g., "an appreciation for what science is, and the applications in the everyday world."

Conceptual Dimension of Scientific Literacy

The scientifically literate person

- has basic knowledge and understandings of science (at the newspaper level)
- understands science involves experimentation
- understands data generated by tests have limitations
- is aware of applications of science in society/life
- is aware of social issues that involve science and technology

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to

- read and write about scientific ideas (in the popular media)
- acquire information and interpret data
- apply science to everyday life and social issues
- make decisions using science

Affective Dimension of Scientific Literacy

The scientifically literate person

- Appreciates what science is
- Appreciates applications of science in the everyday world
- Is inclined to keep up with and dialogue about social issues involving science, from the local to the global level
- Is inclined to act in matters of science in society

Figure 4.12.
An outline of Dr. Gilbert's Dimensions and elements of scientific literacy.

Conceptual Dimension. Acting on science-related social issues requires that one have some awareness and understanding of such issues. This, in turn, requires some knowledge of basic concepts of science. However, the scientifically literate person does not necessarily know a lot of science facts beyond some basic "life skills." In fact, she described the required knowledge as being "at a newspaper level understanding of science," and seems to require considerably less knowledge than recommended by some of the other participants. She also believes it is important to have some understanding of the nature of science, as well as its limitations.

Summary of Procedural and Affective Emphasis

Dr. Gilbert puts a good deal of stress on both Procedural and on Affective characteristics for scientific literacy. Procedural elements she stresses include acquiring information, making decisions, and communicating about science. What is perhaps most distinctive about Dr. Gilbert's view is she says the scientifically literate person is not only aware of science- and technology-related issues in society, but is "inclined to action." She advocates actively seeking out opportunities to use one's scientific literacy, especially in matters related to social issues. By comparison, the other participants seem to describe encounters with science in everyday life and in society as incidental or in a sort of opportunistic-reactive mode, i.e., one acts because it is necessary or because the opportunity presents itself. She also described the required knowledge as being "at a newspaper level understanding of science," which seems to require considerably less knowledge than recommended by some of the other participants.

Summary of Findings

'Core' Elements of Scientific Literacy

The participants in this study discussed a number of 'elements' of scientific literacy, i.e., attributes of the scientifically literate person. In fact, when grouped and sorted (Table 4.2) I found 36 elements in the data. I can classify all the elements into three Dimensions: the Conceptual (with 14 elements), Procedural (with 14 elements), and Affective (with 8 elements).

Table 4.2

A Composite Outline View of Elements of Scientific Literacy Grouped by Dimension.
Most of the designations for 'elements' are taken from the participants' own words, or extracted and condensed from the phrases they use.

Conceptual Dimension of Scientific Literacy	**Procedural Dimension of Scientific Literacy**
The scientifically literate person knows and understands • science concepts • the physical world • science vocabulary • broad principles of science • scientific inquiry • relationships of science to mathematics • limitations of science and technology • the tentativeness of scientific/technological knowledge • science is a social activity • science and technology are human endeavors • the history of science • relationships between science and society • relationships of science to technology • relationships between science, technology, and society	The scientifically literate person is able to • obtain and use information • self-learn science • use science in everyday life • apply science for social purposes • decode science communications • encode science communications • think scientifically • reason and argue • judge validity of claims • make decisions • solve problems • integrate knowledge • engage in inquiry • use some of the tools of science
Affective Dimension of Scientific Literacy The scientifically literate person has a/an • appreciation for science • interest in science • inclination to stay up to date • inclination to monitor and act on science-related social issues • objective, open mind and skepticism • ethical values • self-confidence to use science • appreciation of the world	

The finding that all the ‘elements’ that the participants view as being necessary or desirable for scientific literacy can be classified into just three groups may initially lead one to suspect that there are some broad similarities between the participants’ definitions and descriptions of scientific literacy. In one sense, this is possibly true, because there are certain themes that all or nearly all of the participants seem to include in their views of scientific literacy. If we were to construct a model showing the elements or themes most frequently endorsed by the participants, it might look something like Figure 4.13.

Conceptual Dimension
The scientifically literate person has some knowledge and understanding of

- Science concepts
- Relationships of science and society

Procedural Dimension
The scientifically literate individual is able to

- Obtain and use information
- Apply science in everyday life
- Use science for social and civic purposes
- Understand science-related communications in the public media

Affective Dimension
The scientifically literate individual has

- *An appreciation for and interest in science*

Figure 4.13.
An outline of the most commonly endorsed elements for scientific literacy in the views of the study participants.
The Affective element in italics represents a combination of two closely related elements in Table 4.2.

One is tempted to call the elements in Figure 4.13 the ‘core’ of scientific literacy, since they represent topics agreed on by at least 8 participants (out of 9). That is to say, perhaps these 7 elements represent the essence of scientific literacy, and different people's views of scientific literacy are just variations on a theme. Unfortunately, I do not believe this to be the case. There is some divergence of views even within these 'core' elements, e.g., exactly what 'science concepts' does a scientifically literate person need to know? And precisely how are they to 'use science for social and civic purposes'? Thus, even if all the participants support the elements shown in Figure 4.13, that does not necessarily mean that they include the same knowledge, skills, feelings, etc. in their views of scientific literacy.

Divergence of Views

Comparison of Figure 4.13 with Table 4.2 shows that there are many more elements of scientific literacy that are not held in common than those which are. None of the participants endorse exactly the same list of elements. It is important to note, however, that I tried to avoid prompting participants about particular elements during our interviews. It is quite possible that if presented with a list of elements, participants would have endorsed a larger number than I have coded for them here, thus reducing the number 'not held in common.' But I do not feel such a method would have revealed the participants' fundamental definitions and descriptions of scientific literacy, which is what I am attempting to discern. And I suspect that even if such a 'prompting' method were to be followed, one would nevertheless find there are a few elements about which the participants genuinely disagree. One controversial topic has to do with the ability to "engage in inquiry" on one's own, i.e., to actually "do" science. Drs. Dobson, Howard, and Kellogg all included abilities related to actually doing science as part of their vision for scientific literacy. None of the other 6 participants endorsed this view, and in fact, some spoke against it. Dr. Benjamin said, "except for the future scientists there is no need [for the scientifically literate citizen] to do science." Dr. Gilbert said the scientifically literate "wouldn't have to know how to do science, per se, other than in a very general [way]: 'Scientific research? It does involve usually laboratory tests and [such] things.'

To be honest with you, I think that level of understanding would be sufficient." Therefore, the ability to "do" science is a point of divergence rather than broad agreement.

Perhaps the most controversial element is the Conceptual one I have labeled "relationships between science, technology, and society," or "STS." As Dr. Benjamin puts it, "some people … either agree or disagree with scientific literacy as an outcome depending on how they feel about STS." Drs. Dobson and Gilbert declared they are STS-supporters, and argued extensively for why this viewpoint helps put scientific literacy into context. On the other hand, Dr. Infeld said that including technology and society with scientific literacy is truly not feasible because most teachers "have had no formal training in engineering education. [And] They know practically nothing about sociology." Consequently, she says they do not have the background "necessary to do a good job [of teaching] in that area." Dr. Kellogg said when she thinks 'STS' is "a phrase that has taken on lots and lots of meanings":

> At one point it was associated closely with a curriculum model that Glen Aikenhead had devised … I think defined that narrowly, it's too narrow. But I think it [also] provides entree into this social aspect of science thing [her "third ring"]. And so now when people use it I don't know if they mean the constrained or the broader view. So sometimes when I hear people talk about it, it ends up being a nice handle for this, my three circles [model]. At other times, it's a very specific movement that I find much more constrained than my idea of what this is all about.

Dr. Benjamin says he thinks the STS element actually competes with content knowledge element, giving scientific literacy a sort of split personality:

> It was confused right from the start. See, Paul Hurd was the first person that I've been able to identify who used the term ['scientific literacy']. And Paul Hurd, of course, was somebody who right from the start jumped in against the

> disciplinary approach to science teaching, which is what drove the reforms of the late '50s and '60s. So, Paul Hurd's definition of scientific literacy was one that included science or society and technology into the picture, which is what was pulled out by the reformers who wanted to focus on the discipline. So, right from the start, that always colored the definition of scientific literacy. It was always associated with this STS approach. There were other people who would say, "Yes, <u>but</u>, we can't forget about the content itself." And so you've always had those two opposing ideas running through it, I think.

He concludes that even today, scientific literacy is viewed as "both … the knowledge of the subject, and … the subject in relationship to these social and technical issues that we face." Thus, in some cases the participants are aware of a potential element but they spoke against its inclusion during our interviews.

If one simply counts the "bullets" in Figure 4.13, then one would be tempted to conclude that the Procedural Dimension is the most important aspect of scientific literacy. Indeed, 8 of the participants do emphasize the Procedural Dimension in their views. However, there is a range of emphases among the participants on the Dimensions of scientific literacy. In fact, it is possible to categorize the participants' views according to the emphasis that they place on the elements of the three Dimensions (Table 4.1). In particular, I interpret Dr. Johnson's view to emphasize Conceptual elements (and to a lesser extent Affective elements); Drs. Howard, Andrews, Kellogg, and Benjamin all emphasize Conceptual and Procedural elements; Drs. Infeld, Curtis, and Dobson emphasize Procedural elements for scientific literacy much more than the other two Dimensions; and Dr. Gilbert emphasizes Procedural and Affective elements. When viewed in Table 4.1, these groups almost appear to be a continuum with Dr. Johnson at one end and Dr. Gilbert at the other. Indeed, there is significant overlap between the groups. More importantly, though, there are significant differences, especially between the extremes of the continuum. For example, Dr. Johnson stresses a broad range of conceptual knowledge is necessary for scientific literacy. Dr. Gilbert, on the other hand, says that one can be scientifically literate yet "perfectly ignorant" about most things, because we have "specialists in our society" that we can rely on when we need information. To Dr. Gilbert, it is much more important that a person can obtain information when needed rather than carry it around in one's head.

<u>Possible Emphases Not Observed</u>

Out of all possible combinations of emphases on the three Dimensions, 4 groups were found among the nine participants in this study. I have not classified any of the participants as placing their emphasis on all three Dimensions simultaneously. That is, it appears that Dr. Kellogg was correct when she said, "Each of us emphasize different parts of the model." In fact, only Drs. Andrews and Gilbert have fairly equal emphases on two of the Dimensions; the remainder tends to emphasize one Dimension and perhaps have a secondary emphasis on another. Even so, it is important to remember that all the participants support at least one element from each of the Dimensions in their views on scientific literacy, so perhaps no view of scientific literacy is complete if it lacks some aspect of the three Dimensions.

I find it particularly interesting that none of the participants emphasize Affective characteristics as being more fundamental or important for scientific literacy than elements in the other two Dimensions. There is no inherent reason not to do so. That is to say, it is perfectly conceivable that to be scientifically literate means to be curious about nature, have an appreciation and interest in science, have the inclination to use science, possess the values of scientists, and so forth. However, one must remember that this study sampled the views of only 9 participants, so it is premature to conclude that an Affective emphasis group does not exist.

<u>Other Findings</u>

All the participants agree that the promotion of scientific literacy is the main goal of science education in the United States today. Nevertheless, some of the participants think that the term 'scientific literacy' has either lost its meaning (if it ever had any) or does not fully capture the extent of the goal.

Some participants contrasted the scientific literacy of adults with that of school children, and remarked that the latter is really more important—a point made by Shamos (1995).

Some participants described other goals of science education and contrasted scientific literacy with these other goals. In particular, 8 of the participants made some reference to the goal of ensuring "an adequate supply of scientists, engineers, and science teachers" (NSTA, 1990), and all 8 said that this goal is separate from the goal of scientific literacy.

Summary of Chapter and Preview of Next Chapter

This chapter has examined the attributes of scientific literacy, or 'elements,' coded from transcripts of participants' interviews. Thirty-six elements were derived and grouped into three Dimensions: the Conceptual, Procedural, and Affective. Each participant's view was summarized in a narrative, followed by a discussion of the Dimensions and elements that he or she emphasized. Participants' were grouped by the emphasis that they place on these three Dimensions, with 4 groups resulting. Additional important findings include: none of the participants endorse exactly the same list of elements; Eight of the 9 participants endorse 7 elements in common, with at least one from each Dimension, and these elements might represent the 'core' essence of scientific literacy; there is some divergence of views about the specifics to be included in the 'core' elements; a few of the non-core elements appear to be topics of controversy, including the ability to "do" science ("engage in inquiry") on ones own, and whether or not it is important to understand "relationships between science, technology, and society"; none of the participants view all three Dimensions with equal emphasis, and none see Affective characteristics as being more fundamental or important for scientific literacy than elements in the other two Dimensions.

In the next chapter, I will examine the participants' views on the rationales for scientific literacy, i.e., their reasons for supporting and promoting the goal. I will then construct a framework that combines the Dimensions of elements with the Rationale groups to produce a 'comprehensive' model of scientific literacy. I will compare the participants' individual views with the 'comprehensive' model, and I will show that the participants' views can be categorized into distinct conceptions of scientific literacy based on the rationales and elements they emphasize.

CHAPTER 5

A FRAMEWORK FOR SCIENTIFIC LITERACY VIEWS

Introduction

A question that students often ask is, "Why do we have to learn this?" They are usually inquiring about a particular subject about to be discussed in a class, but the question can also be applied more broadly. Why do students have to learn science in the schools? More in line with the theme of this dissertation study, in this chapter I explore what it is about scientific literacy that makes it a desirable goal in the view of my participants. Ultimately, I am attempting to discern whether different rationale emphases among the participants help explain why they have diverse views on the meaning of the term 'scientific literacy' (as shown in the previous chapter). In other words, if participant X believes scientific literacy is valuable for one reason, but participant Y believes it is beneficial for another reason, does that lead them to two different definitions of scientific literacy? Or can one definition serve more than one purpose?

What people mean by 'scientific literacy' is most likely tied to their reasons for promoting it (Jenkins, 1997; Laugksch, 2000)—or criticizing it as the case may be. Why should the goal of scientific literacy be pursued? Who benefits from scientific literacy? I will refer to statements that in effect answer the question "Why should people become scientifically literate?" as <u>rationales</u>. Terms that other authors use as synonyms for what I am calling 'rationales' include "arguments for," "benefits," "goals of," "intents," "motives," "need for," "purposes," and "reasons." For the purposes of analyzing participants' views on scientific literacy, I will assume that there are multiple rationales for the goal embedded in the context of science education more generally. That is to say, the rationales for the goal of scientific literacy are a sub-set of rationales for teaching science to students (e.g., Atkin and Helms, 1993; Roberts, 1982). For example, one rationale traditionally given for school science is to "ensure an adequate supply of scientists, engineers, and science teachers" (NSTA, 1990). Although a legitimate rationale for science education, this 'science pipeline' rationale is not a motivation for the goal of scientific literacy in the view of my participants.

This chapter has two aims: first, I intend to examine the question, "What rationales do the participants (university science educators) ascribe to the goal of scientific literacy?" I will explore ways to classify the participants' views on the necessity or desirability of individuals and society to achieve the goal of scientific literacy. Secondly, I will attempt to discern how rationales influence the individual views expressed about the elements of scientific literacy. For example, if one person endorses a lot of different rationales, does it follow that his or her definition of scientific literacy is quite broad and all encompassing? Or conversely, does an individual who supports scientific literacy for a particular purpose have a specific and focused view of the concept? My assumption is that the way an educational goal is described by an individual is intimately related to the reasons he or she believes the goal is being pursued.

I am examining the rationales in order to help explain differences in views on scientific literacy. However, it would be appropriate to investigate the rationales for scientific literacy in their own right, because they received serious criticism in the 1990s, especially from Morris Shamos (1995). Shamos (1995) says there is little to no evidence that scientific illiteracy hinders nonscientists in their personal or professional lives. Therefore, he concludes it is time to abandon "scientific literacy" and switch to another more defensible, practical and achievable goal, such as the one he proposes to call "scientific awareness." By dismissing the rationales for scientific literacy, Shamos is bringing into question "the fundamental goal of science education" (Bybee, 1997, p. 46), and such a criticism should not go unexamined.

Preview of Findings

I will show that the rationales the participants gave for the goal of scientific literacy can be grouped into at least 4 Domains: Practical Social Benefits, Practical Individual Benefits, Benefits to Humanity, Personal Aesthetic Benefits. It is important to remember, as Laugksch (2000) cautions, dividing rationales into groups "may paint a somewhat overly neat and simplistic picture of a complex concept, for overlap between the various arguments can and does exist" (p. 87). That is, the rationales above are not completely mutually exclusive, either within a Domain or between Domains. A given individual may view any or all of the rationales as legitimate, although some will be given higher priority than others.

Next, I will combine the four Domains of Rationales for Scientific Literacy with the Dimensions of Elements of Scientific Literacy derived in the previous chapter to form a Framework for Scientific Literacy Views. I will show that my participants' views can be classified into as few as three Categories using the Framework, although a number of other potential Categories also exist.

In the next section, I will explore an initial framework for classifying scientific literacy rationales outlined by one of my participants.

Initial Framework for Rationales

Dr. Infeld's Three Types of Rationales

The participants sometimes directly expressed their opinions about the rationales for scientific literacy. Dr. Infeld gave a particularly succinct statement that will serve as a useful starting point in the search for a way to classify their views. Dr. Infeld said, "If you look at goals of science education over the past hundred years, one of the things that you see is that the goals don't much change. [Instead,] what changes is the order in which the goals are presented." Note that she is using the term "goals" in the sense that I am using the term 'rationales,' because her next statement was, "And basically the one that is sort of at the top of the list now is productivity. And the productivity goal is the one that I think fueled the current reform. …We were scared to death that Japan and Germany were outdistancing us in the world economic market." In other words, one rationale for promoting science education is that it somehow aids the economy of the United States. A little later, she explained further:

> So to get back to the goals, I think the one that's on top at the moment and has been on top for a while is the sort of view of <u>being a productive citizen</u>. Then there's … <u>engaging in civic responsibilities</u> is a second one. A third one is sort of <u>personal life</u>. Not mixing Clorox and Drano in the toilet kind of thing. Making reasonable decisions about [whether to take] hormone replacement therapy or not kind of things are the personal kind of stuff. And the one that's sort of at the bottom of the list in terms of the goals for school science is preparation for life in science—sort of the 'little scientist' thing. Now I think all of the first three combine in what I think of as science literacy. It's a definition of the kind of science that ordinary people need to be productive, good citizens and take care of the science-related parts of their daily lives.

Thus, Dr. Infeld envisions 3 types of rationales for scientific literacy: it helps one to be a productive citizen, engage in civic responsibilities, and in personal life. She also makes an important point that it is possible to think of the rationales in a prioritized arrangement, but the priorities are subject to change. There may be a dominant rationale for science education as a whole, such as the "productive citizen" rationale. But it is also possible that individual science educators have their own priorities.

I will now explore these three tentative types of rationales in statements from the other participants, before turning my attention to finding other possible rationales.

<u>Productive citizens</u>. Dr. Infeld says she believes the rationale for the goal of scientific literacy that is "on top at the moment and has been on top for a while is the sort of view of <u>being a productive citizen</u>." She spoke of the "productivity" in a national context, saying that the reason it is "on top" is the United States became concerned (in the 1980s)

about economic competition from other countries. Other participants also made statements in reference to this rationale. For example, Dr. Benjamin said that the United States became concerned "about our economic position in the world" in the 1980s, and that concern contributed to the present prominence of the goal of scientific literacy in science education. However, he personally does not endorse enhancing national productivity as a fully legitimate rationale, because "the relationship … between [our] educational system and our economic development" seems tenuous, at best. He says, "It's a little hard to argue that they're connected when [our] students are scoring at the bottom on international tests and our economy is the strongest in the world." He thinks others are realizing this contradiction, and therefore this concern with national productivity has lessened somewhat. Nevertheless, while there is a national aspect of productivity that Dr. Benjamin discounts, there is also a personal aspect of productivity that he favors. He said that he thinks the primary goal of education is "personal development," and one of the main aspects of this goal—to which scientific literacy contributes—is "preparing individuals for the world of work in a certain practical sense." Dr. Howard also spoke of the personal benefits of scientific literacy, saying it helps individuals "in terms of their employment." On the other hand, Dr. Andrews said scientific literacy helps people to be "workers," but he seems to have been referring to a more nationalistic perspective, because he made this reference in the context that educators must decide "What's going to be the appropriate kind of process knowledge that people need in order to be scientifically literate, to be functional citizens and workers and constructive members of our society"—all rationales aimed at the societal rather than personal level. Thus, the "productive citizens" rationale has two possible aspects, one on the personal level and one on the societal or national level. There is no inherent reason why these two aspects are mutually exclusive, i.e., an individual can believe both that scientific literacy benefits the individual in his or her job, as well as that it benefits the nation in terms of increased productivity.

Engaging in civic responsibilities. Several participants referred to scientific literacy as necessary for "democracy" and "society", or what Dr. Infeld called "engaging in civic responsibilities." For example, the participants said scientific literacy is necessary because:

- "…everybody votes. And … if we're going to make a democracy work, then we have to have an educated population." (Dr. Andrews, citing John Dewey)
- "…in a democratic society, individuals should be able to participate in the conversation about their world that they live in, part of which is a scientific world. … As a fully participating member of society, they have to share at some level--and each of us is going to participate at a different level--in the conversation about the world that they live in." (Dr. Benjamin)
- "… [it enables them] to participate in a democratic society." (Dr. Dobson)

The participants were not very clear exactly how scientific literacy helps people participate "in a democratic society," but it was nonetheless apparent that they believe this to be the case.

Personal life. The examples Dr. Infeld gave in connection to scientific literacy helping in personal life had to do with making individual decisions: "Not mixing Clorox and Drano"; and whether to take "hormone replacement therapy or not." Similarly, Dr. Benjamin said, "In our society we get a lot of information passed onto us regarding health issues in the print medium and on television, [and] to some extent orally by doctors and the medical profession. And from tradition. … Our own health and well-being are certainly important issues for us to be involved with," and one would presume, important issues to make personal decisions about. Dr. Andrews said scientific literacy helps individuals decide how much credence to give to "television … ads" and printed materials found at "the checkout counter at the supermarket." Dr. Dobson said scientific literacy provides one with "logic, the ability to think & decide." However, it was not always clear that the focus of the decision-making was on a personal level. Dr. Kellogg, for example said, “if people could attack, interface with, approach problems with an understanding in problem-solving, with an understanding of reasoning, with a reliance on evidence, … they would ultimately make wiser decisions.” These decisions might be personal, but they might also be group decisions.

Scientific literacy is thought to have other practical benefits in addition to being able to make decisions. Dr. Johnson, for example, said:

> There’s a whole bunch of reasons why we want people to be scientifically literate in the context of knowing, using, and lifelong desire to want to learn more about it. One is just the simple practical aspect knowing how people are able to do things. It’s important in your life. It’s nice to know how the computer works when you’re using it, so … if something goes wrong, you can fix it. So it’s just kind of practical. It’s practical for your health. You should know about side effects of things. And what drugs [are able to do]. What disease is like. …The practicality of science literacy is obvious. If somebody knows about diseases, it’s useful. … It’s good to be scientifically literate because people that know science will be able to deal with the everyday world in a scientific way.

Similarly, Dr. Howard said scientific literacy enables one “to understand how certain things work.” Dr. Andrews said scientific literacy helps individuals understand “how our human body works,” which contributes to the maintenance or betterment of our “health” and “safety.”

Another way participants said scientific literacy affects “personal life” is by giving one a better appreciation for life, nature, and the world. They said scientific literacy:

- “[is] important from a philosophical, and in some ways, even a recreational view, an appreciation view. An appreciation of the world around us.” (Dr. Andrews)
- enables people “to live a full life, a rich life, because of their knowledge base, because of their experience, because of their understanding.” (Dr. Howard)

- benefits individuals "in terms of understanding the natural world. Kind of the aesthetic, the enjoyment of it." (Dr. Howard)

Some also said that science is interesting, and for that reason alone scientific literacy is a worthwhile pursuit:

- "[One] reason for science literacy is just to know science. … In other words, it's one thing to be practical and know about science because it can help you in your own life. It's another thing to know something just because it's nice to know it." (Dr. Johnson)
- "science is and of itself intrinsically interesting" (Dr. Kellogg, referring to one rationale given by the *Standards*.)

Thus, scientific literacy is valuable because it helps people <u>make decisions</u> and <u>understand how things work</u>, gives one a greater <u>appreciation for life</u>, and <u>science is inherently interesting</u> and pleasurable to know.

<u>Overlap Between the Groups</u>

Sometimes, the participants closely associate rationales that I have tentatively separated into different groups above. For example, participants spoke of rationales related to "engaging in civic responsibilities" and "being a productive citizen" in the same sentence. Some representative comments include:

- "science is a very important part of our culture … not only is it important for voters, but it's important economically." (Dr. Andrews)
- "[scientific literacy is needed] to be contributing citizens, [and] to be economically self-sufficient" (Dr. Howard)

Seeing as civics (politics, democracy), culture (society), and economy (especially on a national level) are potentially linked in participants' statements, it is perhaps not advisable to think of the "civic responsibilities" and the "productive citizens" groups of rationales separately. Even the titles I gave to these groups of rationales show how closely they might be associated, i.e., "<u>civic</u> responsibilities" and "productive <u>citizens</u>."

Therefore, in the next section I will explore the possibility of arranging the rationale groups in a more useful way.

Foci of Rationales

I noted earlier that the "productivity" rationale has a dual nature, i.e., it can refer to personal productivity or economic productivity on a national level. Thus, it is the group level focus versus a focus on the personal level that may be the important aspects around which to organize part of a framework for categorizing rationales. This is exactly the point of view adopted by Laugksch (2000) for organizing the "common arguments that have been suggested in favor of scientific literacy" (p. 84). Laugksch reviewed the published literature in English on the concept of scientific literacy, and decided that the rationales for scientific literacy fall into two general groups, which he calls a "macro view" and a "micro view." The macro view "relates to the alleged benefits that accrue to the nation, science, or society," whereas the micro view "relates to the enhancement to the lives of the individual" (p. 84).

Dividing rationales into "micro" and "macro" views is a useful tool, but I do not believe it is quite discriminating enough. For example, I find the rationales in the "personal life" ("micro") group can be usefully divided into two groups: those that have a utilitarian or practical focus, and those that have a more intangible, abstract focus. The practical focus includes rationales having to do with making personal decisions and understanding how things work so that one can deal with them in everyday life. I will refer to this type of rationale as belonging to the 'Practical Individual Benefits Domain.' The abstract focus encompasses rationales having to do with a greater appreciation for life and finding science inherently pleasurable. I will refer to this set of rationales as the 'Personal Aesthetics Benefits Domain' (borrowing Dr. Howard's term, "aesthetics"). Thus, these rationales can all be viewed as fitting Laugsch's "micro" view, but can be further distinguished by their focus on the practical or the abstract.

Dividing the personal (or "micro view") rationales into practical and abstract foci begs the question of whether the group (or "macro view") rationales can be similarly divided. Indeed, I believe they can. All the group-level rationales given above can be thought to have a 'practical' focus, e.g., 'participating in a democracy' and 'contributing to the national economy.' I will refer to these rationales as belonging to the 'Practical Social Benefits Domain.' But there is another set of group-level rationales not revealed previously, of which this framework makes us aware. For example, Dr. Benjamin described science education as part of an overall education, the "primary goal" of which is "to understand the world. … And if you're taking a humanistic approach to education then it's to understand our experience of the world as human beings. … That is why we're studying anything in the first place, because it's important to us as human beings." Similarly, Dr. Kellogg said: "I have a fundamental belief …that humans are a rational animal, [and] the procedural [part of scientific literacy] captures the rationality of who we are." The point of statements such as these is that scientific literacy somehow contributes to our humanity, a goal that is certainly not 'practical' and might be said to be more 'abstract' in nature. I will refer to the abstract-group type of rationale as belonging to the 'Benefits to Humanity Domain' of rationales.

Several participants saw the Benefits to Humanity rationales as being particularly important because they apply to all people, no matter where they live and regardless of what science knowledge or technological applications are available to them. As Dr. Benjamin put it, each society or culture has to "define scientific literacy for them[selves] somewhat differently" depending on their needs and the extent of science-related issues in their lives. Dr. Dobson said that even people in less developed nations need scientific literacy because its "features … are human traits." Dr. Kellogg said that from her point of view scientific literacy is beneficial for "everyone on Earth," regardless of where they live, because "being human is being human."

Overview of the Intermediate Framework

So far, I can classify rationales given for the goal of scientific literacy into at least 4 groups that differ in "focus." The foci lie along two "axes" that I will refer to as the "Scale" of the focus, and the "Utility" of the focus.

- Scale focus: Some rationales are focused on the benefits of scientific literacy for the individual, while others focus on benefits for a group (society, nation, humanity).
- Utility focus: Some rationales focus on practical or utilitarian benefits of scientific literacy, while others are abstract, i.e., they focus on intangibles, such as aesthetic, moral, and intellectual advantages.

Viewing the rationales in terms of the four foci above gives us a new perspective, and leads to four Domains of rationales (Table 5.1). The resulting Domains are "Practical Individual Benefits," "Practical Social Benefits," "Personal Aesthetic Benefits," and "Benefits to Humanity."

Table 5.1
Domains of Rationales for Scientific Literacy.

Foci of Rationale Domains		Scale of Focus	
		Individual	Group
Utility of Focus	Practical	"Practical Individual Benefits" Domain	"Practical Social Benefits" Domain
	Abstract	"Personal Aesthetic Benefits" Domain	"Benefits to Humanity" Domain

There is no inherent reason that the foci along a given axis in Table 5.1 have to be viewed as continua with mutually exclusive ends. For example, it is possible that the scale of a rationale can have both social and personal foci, such as the ‘productivity’ rationale. Similarly, the rationale for ‘rational thinking’ can have both practical and aesthetic functions. However, if the speaker intends for the listener to understand the intent of the rationale, it would be wise to clarify exactly what utility and scale of their purpose includes. For example, just saying that scientific literacy contributes to ‘productivity’ essentially says nothing, for one does not know if this is on a personal or national level.

Participants’ Rationale Emphases

Now that we have a way to classify rationales espoused by the participants, it is necessary to see which rationale domains each participant actually emphasizes. I will briefly review the rationales given by each participant separately. The participants are discussed in the same order they appear in Chapter 4 (see Table 4.1), beginning with Dr. Johnson.

Dr. Johnson

Dr. Johnson’s short definition of scientific literacy--“people [should] know about science and they can use it in their everyday lives”—reveals one of his main rationales for the goal. That is, he believes everyone should use science in their everyday lives. For example,

> there’s … the simple practical aspect [of] knowing how people are able to do things. It’s important in your life. It’s nice to know how the computer works when you’re using it, so you can, if something goes wrong, you can fix it. So it’s just kind of practical. It’s practical for your health. You should know about side effects of things. And what drugs are able to [do]. What disease is like.

In addition, “everyday you can read about science on the web or in the newspapers. There’s a lot more visible science now than there ever was. … You can turn on the *TV* and there are health programs … I mean, every channel has something about science now. There’s a lot about space,” for example. He concludes, “It’s good to be scientifically literate because people that know science will be able to deal with the everyday world in a scientific way."

Another rationale Dr. Johnson seems to hold for scientific literacy relates to opportunities it provides. That is, scientific literacy provides a person with more opportunities than one would have without scientific literacy. Recall that Dr. Johnson thinks scientific literacy mainly involves an awareness and/or knowledge of a broad range of science topics. Consistent with this view, he says when he teaches freshmen science courses, he tries to cover as many topics as possible, so that "my students in my class … know a little bit of everything I can possibly teach them." That way, if they hear about something of interest to them, they can follow up on it. He says, "I don't want my students as freshmen end up as seniors and suddenly say, 'That's an electron microscope? I should have taken a course in that. If I'd known about that when I freshman …'."

Dr. Johnson believes another "reason for science literacy is *just to know science*. … In other words, it's one thing to be practical and know about science because it can help you in your own life. It's another thing to know something just because it's nice to know it." He says some things are just "interesting," and if you are a "fountain of … knowledge" then you might gain the "respect" of others for being "smart." On the other hand, he says there are many people that "frown upon intellectuality," so that may be one reason many people do not learn more science. For example, Dr. Johnson related an incident that illustrates how he believes his scientific literacy once prevented him from an opportunity to serve on a jury. The case involved a medical malpractice suit. An attorney asked him, "'Could you listen to expert witnesses on the stand? Can you actually accept what they say?'" He replied, "not only could I accept what they say, I could understand what they say, and I could explain it to the other jurors." According to Dr. Johnson, "they immediately kicked me off" and replaced him with someone who had never heard of the disease involved in the case. So sometimes, according to Dr. Johnson, "scientific literacy is frowned upon in our community. Lawyers don't seem to want somebody on a jury who knows something."

Summary. Dr. Johnson gave several examples of how scientific literacy has Practical Individual Benefits, including being able to fix things (like a computer) and making decisions about one's health. He also said that knowing a broad range of science might give one more opportunities in life. A second type of rationale that Dr. Johnson gives for scientific literacy is that a person might find science "nice to know." I classify this latter rationale as belonging to the Personal Aesthetics Benefits Domain. Finally, Dr. Johnson gave an example where some people might think scientific literacy might not be a good thing (although he disagrees), specifically in "engaging in civic responsibilities" which fits into the Practical Social Benefits Domain.

Dr. Howard

Dr. Howard says scientific literacy is something everyone "absolutely" needs "to be contributing citizens, to be economically self-sufficient, and aesthetically." He says that "science is part of one's tool bag," and that scientific literacy helps:

> just in terms of understanding the natural world. Kind of the aesthetic, the enjoyment out of it. Being able to understand how certain things work. But also in their own lifestyle in making choices in terms of nutrition, and choices of the household. On and on. Also in terms of their employment. Across the board.

He thinks "when you understand it, you're more comfortable with it. You can use it better. Just makes a richer life." I asked Dr. Howard what society would look like if everyone became scientifically literate in the future. He replied:

> Oh, it will be better in all regards. The environment will be better. Quality of living will be better. Conversation and discourse will be richer. Economically probably … more productive. It's kind of--hell, it's utopia. And it may not look any different, other than people are more satisfied, more aware of their

> place in world and how it operates. And, it's hard to say, you know, if we were sitting here and talking about English literature, and understanding Shakespeare and such—[would that] make the world a better place? I don't know.

He said that citizens in developing countries probably need scientific literacy even more than people in the United States: "they're just facing all kinds of problems where some knowledge of science among their voters or citizens and their political leaders is essential." He recognizes that people's problems are not going to be totally resolved by becoming scientifically literate, but they could certainly be helped.

Dr. Howard sees scientific literacy as a moral goal. That is to say, not only does everyone need scientific literacy, but they deserve it:

> In the United States I think you could make the case that we have a broad-base literacy in science. And so if 20 percent are illiterate in science, the rest of us can carry them. And you could probably make that argument, BUT you're dooming those people to a certain kind of existence that we shouldn't tolerate.

For example, he spoke about the health problems and costs related to smoking, and how smoking rates might decline if people were more scientifically literate. In other words, increased levels of scientific literacy would improve people's health and lives, which would benefit them personally as well as benefiting society in general.

<u>Summary</u>. Dr. Howard says scientific literacy is something everyone "absolutely" needs:

- "to be contributing citizens"—a Practical Social Benefits rationale.
- "to be economically self-sufficient"—a Practical Individuals Benefits rationale.
- "aesthetically … just in terms of understanding the natural world … [and deriving] enjoyment out of it"—a Personal Aesthetics Benefit rationale.

He also said that if everyone became scientifically literate, the "Quality of living will be better," and in fact it would be "utopia." These comments when viewed in the context that he thinks denying scientific literacy to anyone means "dooming [them] to a certain kind of existence that we shouldn't tolerate" clearly demonstrate that he also believes scientific literacy has Benefits to Humanity. Thus, Dr. Howard gives examples that fit into all four domains of my framework of rationales for scientific literacy.

Dr. Andrews

Dr. Andrews explicitly mentions several purposes for scientific literacy. First there are personal and practical applications of scientific literacy. For example, he says scientific literacy helps individuals understand "how our human body works," which contributes to the maintenance or betterment of our "health" and "safety." He also says that scientific literacy helps individuals understand and evaluate media information, such as "television … ads" and printed materials found at "the checkout counter at the supermarket," which presumably protects the individual against false-claims that could injure the individual in some way.

Scientific literacy also helps people to be "workers," i.e., it contributes to job skills in today's modern workforce. This latter aspect has dual connotations, namely, it helps the individual but at the same time helps the nation-state's economy. Dr. Andrews might have been more concerned with the latter, because he includes the "worker" rationale in the same sentence as being "functional citizens and workers and constructive members of our society." Thus, a second focus of Dr. Andrew's rationales for scientific literacy is at the socio-national level, or that is to say, at a level greater than the individual. For example, Dr. Andrews also mentions "environmental problems" as being something scientifically literate individuals could be in a position to better address.

Dr. Andrews alluded to a non-practical purpose of scientific literacy, i.e., that it somehow enables people "to live a full life, a rich life, because of their knowledge base, because of their experience, because of their understanding." Unfortunately, I did not follow up on this rationale during our interview, so it cannot be more fully elaborated here.

I asked Dr. Andrews to comment on Shamos' assertion that "the goal of science literacy for all is unobtainable and should be abandoned." He replied,

> I think I'll quote or defer to Rodger Bybee's point of view on this. … He indicated that the goal of science for all is one we should adhere to. And the reason we should adhere to it is it is like justice for all. It's a goal. And as long as you keep that goal in mind you're going to progress in the right direction. It may be practically unobtainable at this moment. But if we keep it as a goal, it's a challenge, because we have a tremendous amount to learn in order to be able to achieve that goal … And we have to work on it.

He concluded, "I think that's one of our great research challenges, is to be able to figure this out."

Dr. Andrews very explicitly spoke against including the goal of developing scientists as being part of the domain of scientific literacy. He did, however, acknowledge that this "pipeline" goal was an underlying agenda in the past that may still exist today. For example, he said that due to the "space race" in the 1960s,

> we had to have smarter and better engineers and scientists. And, we [science educators] were directed toward that. The [NSF-sponsored] elementary programs and middle school programs were designed to help increase a broader base of scientific literacy. But the hope was that it would, it would increase the flow into the pipeline of science.

He says that science educators at the time were well intentioned, but nevertheless were promoting an "elitist" agenda: "I don't think that people were willfully saying, 'well, we're being elitist.' But I think it was part of a long cultural indoctrination--that there are people who are good in science" and those are the ones science educators focused on the most, while giving relatively little attention to the majority of students. This view is still predominant at the college level:

> if you go … and talk to people in the chemistry department [at a university], they're not concerned with deep understanding on the part of all. They want a few good students who can go and get Ph.D's. And general scientific literacy on the part of the whole community is—you know, you could find people in science departments who are concerned about that, but they're not commonplace.

However, Dr. Andrews thinks at the pre-college level the idea that science is "for all" has increasingly gained popularity since the 1960s. He thinks that this focus on "all" students includes concerns for creating "gender equity … ethnic and racial equity, [and] social equity with science." Broadening the dimensions of what is taught as science in schools, and making school science more "interesting" by presenting it in "multiple ways," and viewing children "as a community of learners" are just some of the strategies that have "emerged in the past few years" to work towards the goal of "science for all," as opposed to science for the "few."

Summary. Dr. Andrews gives examples that seem to support all four types of rationales for the goal of scientific literacy. In the 'Practical Individual Benefits' domain of rationales, he includes such things as understanding our bodies and health, safety issues, and evaluating claims in the media. Scientific literacy also contributes to personal job skills. Second, Dr. Andrews lists some rationales that fall under the heading of 'Practical Social Benefits' of scientific literacy, such as becoming "functional citizens and workers and constructive members of our society," as well as addressing "environmental problems." Dr. Andrews alludes to a Personal Aesthetic Benefit of scientific literacy, namely, that it enables the individual "to live a full life, a rich life, because of their knowledge base, because of their experience, because of their understanding." Finally, Dr. Andrews comparison of the goal of "science for all" to "justice for all" seems to be a reference that fits in the Benefits to Humanity domain. Dr. Andrews spoke against including the goal of developing scientists as being part of the domain of scientific literacy (although it is a legitimate goal of science education more generally, especially at the college level).

Dr. Kellogg

Dr. Kellogg says that she thinks "that 'science literacy' is a phrase that somebody … invented to capture the growing phenomenon of the importance of science in the world beyond the classroom and the laboratory, … [as well as] the procedural aspects of science. Dr. Kellogg said that

> in the last 30 years there has been a dichotomy in people's thinking about what the purpose of science education is. And that if I made up bumper sticker slogans I would talk about 'science for the pipeline' and 'science for science literacy.' Science for the pipeline sees science as a relatively elitist activity that only certain people can engage in. And these people make unique contributions to society through research. And because it's elitist, one of the purposes of science education is to cull out those who are qualified, who meet these requirements. And then there's a second camp that sees science that has a huge impact on what we do everyday--the world we live in, the way our bodies function, the way our families function, the way we build our house, political decisions--that have to do with what I call 'external features of science.' And then there are cognitive features of science, like relying on evidence, structuring arguments based on warrants, that everybody does these things and this is the science literacy camp.

The view of science as an activity for specialists seems to persist, and may be a barrier to achieving scientific literacy. Dr. Kellogg says, "there are too many people in the public who have the image of science as this elitist thing that they studied in school, using expensive equipment, that you memorize the names and forget. And their images and memories are a big constraint to a social acceptance of a different reason for teaching science." She says, "I have an intuition, a hunch, that if we really taught for scientific literacy, the pipeline problem would take care of itself."

Dr. Kellogg says, "if you look at the front of the *Standards*, … the first [reason it gives for studying science] is that science is in and of itself intrinsically interesting." [I believe she is referring to one of the "goals for school science" that will "define a scientifically literate society," namely, to "experience the richness and excitement of knowing about and understanding the natural world" (NRC, 1996, p. 13).] She says what is interesting about science varies for different people. For scientists, it is "the intrigue of engaging themselves with a puzzling situation, or a problem situation. Whereas for the teacher it [is] 'oh, let's do all these fun things.'" This disparity, incidentally, is "a constant source of tension" between scientists and science teachers according to Dr. Kellogg.

Dr. Kellogg said: "I will always believe that all people could benefit from knowing science, that all people would be empowered by knowing science, that knowing science is a valuable process." In another part of the interview, she said:

> I think scientific literacy has a potential to benefit people primarily by giving them understanding and facility in this procedural part. That if people could attack, interface with, approach problems with an understanding in problem-solving, with an understanding of reasoning, with a reliance on evidence, that they would ultimately make wiser decisions. And they would recognize that they can't do the problem-solving and the reasoning without taking into account the facts … and the human impacts of what they are doing. I mean since I have a fundamental belief …that humans are a rational animal, the procedural captures the rationality of who we are. … And I think if we used our rationality, we'd make wiser decisions, and ultimately we'd be happier.

She said that from her point of view scientific literacy was beneficial for "everyone on Earth," regardless of where someone lives, because "being human is being human."

Summary. Dr. Kellogg, referring to the *Standards*, says "science is in and of itself intrinsically interesting." This rationale fits into the Personal Aesthetic Benefits domain in my framework. She also places herself in the "camp that sees science that has a huge impact on what we do everyday," ranging from "the way our bodies function" to making "political decisions." These two rationales belong in the Practical Individual Benefits domain and Practical Social Benefits domain, respectively. Finally, she says "that all people could benefit … [and] be empowered by knowing science," which falls into the Benefits to Humanity domain. Thus, Dr. Kellogg makes reference to rationales that fit into all four domains in my framework. Like many of the other participants, Dr. Kellogg also acknowledges that while "science for the pipeline" exists as a purpose for science education, it does not serve as a rationale for scientific literacy.

Dr. Benjamin

In Dr. Benjamin's view, scientific literacy means that a person can "*take part* in the conversation about science that takes place in the society that they live in." He later clarified that he is mainly thinking about scientific literacy in terms of "an advanced, industrialized, democratic society," such as is found in the United States. He thinks

> Our world is clearly a scientific world. It is an analytical world. We use analysis in science, but we also use analysis in almost everything else that we do, even literary analysis. We break up works of literature, and poetry, and art into their component parts. It's not good enough just to look at a work and to write some kind of narrative that expresses our feelings about it. You know, it's analyzed. So it's pervaded everything we do.

Thus, he believes a purpose for scientific literacy is to help individuals make sense of and participate in our modern scientific society.

As intimated above, another purpose for scientific literacy is to help the individual participate in democracy.

> in a democratic society, individuals should be able to participate in the conversation about their world that they live in, part of which is a scientific world. That's pretty much my claim, that they need to be able to take part in that conversation. As a fully participating member of society, they have to share at some level--and each of us is going to participate at a different level--in the conversation about the world that they live in.

He continued:

> it's true of all democratic societies. Is it true of non-democratic societies? I think when you live in a democratic society and you value democracy then you value that for everyone, not just yourself. And you hope that people who live in countries where democracy is not practiced will be able to free themselves—will be free, and have the same ability to participate in the conversation about their world that we do here.

Later, he added: "I think a democratic society is a humanistic society. It's one that values persons. And it values intellect. It values rational thought. It values careful, critical thinking, and so on. So, I think that's mainly where I'm coming from when I use the word humanistic." Presumably, then, scientific literacy contributes to these things that are valued in a democracy and in a humanistic society. He made it clear, however, that he is more interested in promoting the benefits of scientific literacy to the individual, rather than to society at large. As he puts it, "I am not personally that interested in the political aspects of science education. … I think of it much more in terms of personal development." In his view, "personal development" is a long-standing goal of education in general:

> I would argue that from the beginning of our educational system in this country, education has been primarily for personal development. That can be defined in a kind of broad sense of genuine personal satisfaction, or in a more utilitarian way of preparing individuals for the world of work in a certain practical sense.

He says the shift in focus from personal development to the society at large is a product of the "rise of Progressive philosophies in education," especially "during and following the second World War." At that time, "when the federal government became much more involved in education in setting an agenda for the science education program," the focus shifted to educating "individuals who could relate to each other, and interact with each other in society. … The idea [was that] we were creating individuals who would then be responsible citizens, who would build a society around individuals who were competent and knowledgeable."

Dr. Benjamin believes this focus on society has actually developed into an entirely separate goal of education. He says following the second World War:

> national security came to be a concern of the federal government. Before that it never was. It was always personal development. Education was for personal development, not for these goals that are determined by the state. And, of course, if you look at science education today, you see almost all of the major projects that are going on--this certainly was during the '60s for sure, the NSF funded projects--but even today, these are national standards that we have here. National standards are not written for the development of individuals and individuals' competence, but somehow to build the society in a certain way.

And another society-level purpose for increased scientific literacy became prominent in the 1980s, when the United States became concerned "about our economic position in the world." He thinks this concern has lessened somewhat, however: "there's a lot of talk now about what the relationship is between educational system and our economic development. It's a little hard to argue that they're connected when students are scoring at the bottom on international tests and our economy is the strongest in the world." It is a strange phenomenon that if the economy goes bad, the education system receives the brunt of the blame, but when the economy is good "They say there is no relationship."

Similar to Dr. Andrews, Dr. Benjamin said "the advancement of the [science] discipline itself" is not part of the rationales for the goal of scientific literacy, although it is certainly was a dominant goal science education at one time. As he puts it, "there was a lot of disciplinary talk in the '60s that we don't have as much of now." In his view, an important "first step" in better defining scientific literacy is to

> separate the two major components. The first component is the public's understanding of science, and the second component is the understanding of science for the specialist. … We need to think differently about how to educate perspective scientists and perspective citizens who are not going to be scientists.

However, these differences in education for the two tracks need not show up until students graduate from high school:

> You could possibly draw the line at college. You could say that everyone up through high school should be educated in a common way and that beyond that then you have the opportunity to specialize. You might even feel comfortable with a model that had everyone having the same basic education even a couple of years into college before specializing. There are a lot of people who feel that the first two years of college should be essentially a general education, and that people should have pretty much the same kind of experiences in college at that time, and then choose later.

Dr. Benjamin says he thinks Morris Shamos calls for separate education tracks for science specialists and non-specialists, and for that reason his views will ultimately be rejected (or ignored):

> I think what most educators would have a difficult time with is his desire to create a system that treats people differently, that would not aim toward a general understanding science related issues for everyone. That he would propose that certain people, the masses of general public, would learn only about the scientific enterprise, and not the scientific processes, knowledge, etc.,

> themselves. It's just so hard for me to see what is gained by that. I just don't understand the point of that. I don't understand the point of learning about science and it's role in society, and not knowing the concepts themselves.

He concludes, "I can't grab onto that idea."

Dr. Benjamin views the public support of science as a goal of science education, albeit it is a separate goal from scientific literacy and one that is less emphasized in science education today:

> something that goes alone with [the science pipeline goal of the 1960s was] trying to get the public at large to be sympathetic to what scientists are doing. Almost as a political activity, you put your best face forward and you try to get the public to appreciate [science], so that they will fund scientific research, that they will be sympathetic to the experiments and exploration in science that you're doing. This was particularly important right after we had a number of frightening events occur with science. … Certainly, nuclear warfare is a threat, the cold war is a real issue, [as well as] war itself and the kinds of wars that are fought and potentially will be fought. We'd become afraid of what science might produce, and so there [was] a concerted effort to make sure that the public had a positive view of science so that science could be advanced.

He says now that the cold war is over, however:

> I certainly don't see as much of that [i.e., public appreciation] as an explicit goal today as it was at one time. I don't see many people writing about it or being concerned about it. … Maybe I'm not accurate on this, but I think I we may recognize that science is well respected by the general public. Yet they know that science has produced enormous advances—I'm being careful here not to … put too positive a spin on it—, but I think they recognize that it is part of this enormous growth in our technology and all of the information technology that's come, all of the medical advances that have come. All of this is due to science,

> and they recognize that. They understand that there's some risks, but have become accustomed to dealing with those risks so that we as science educators don't feel the same kind of need to trumpet our product in the way we might have in the past.

Thus, it is not a purpose of the goal of scientific literacy to support the advancement of science itself, as some of the later participants may suggest.

To Dr. Benjamin, the goal of scientific literacy is actually an expression of "a basic value." Therefore, he does not believe the goal is—or needs to be—based on empirical evidence:

> It's not a question of whether scientific literacy is a good thing or not--that's the value. The question is whether or not the methods that are used in school lead to an outcome that is a scientifically literate person. That is, somebody who can participate in discussions about scientific issues as adults. So, what you could do empirical studies on is the effectiveness of the educational approach. You can't do studies on the effectiveness of the outcome, because I think the outcome is simply a statement of what you value.

Thus, scientific literacy can be researched—provided that it is operationally defined—, but deciding whether or not it is a proper goal of science education is not "really testable."

Summary. Dr. Benjamin includes a number of rationales for scientific literacy, as well as for science education more generally. However, he did not necessarily endorse all the rationales he spoke about. He said that first and foremost he is concerned with education for personal development, and in this connection scientific literacy rationales he endorsed include such things as:

- personal satisfaction—a Personal Aesthetics Benefit rationale
- preparation for the world of work—a Practical Individual Benefit rationale

He also supported some rationales that connected the individual to a larger group, although he emphasized that he was more interested in the personal side of these purposes:

- "take part in … an advanced, industrialized, democratic society"—a Practical Social Benefits rationale
- Later, he added: "I think a democratic society is a humanistic society. It's one that values persons. And it values intellect. It values rational thought."—a Benefits to Humanity rationale.

Thus, Dr. Benjamin endorses purposes that fit into all four domains of rationales for scientific literacy. However, he did not give as much emphasis to the group focus as he did to the individual/personal focus of those rationales, especially on the Practical Social Benefits side. Consider, for example, that he discussed but did not seem to endorse rationales such as the following:

- Developing "responsible citizens, who would build a society around individuals who were competent and knowledgeable."
- National security
- The "economic position" of the United States in the world

In addition, he also spoke against the "science for the specialist" and 'public support of science' rationales.

Dr. Infeld

Summary. Dr. Infeld's rationales have been previously described (see Initial Framework for Rationales earlier in this chapter). They included three "goals" for scientific literacy: to be a productive citizen, engage in civic responsibilities, and to use science in personal life. The first two of these fit in the Practical Social Benefits domain, while the latter is a Practical Individual Benefit. A goal for school science that she did not include under the banner of scientific literacy is "preparation for life in science."

<u>Dr. Curtis</u>

Dr. Curtis' views on the rationales for the goal of scientific literacy require some more interpretation on my part than for most of the other participants. This is largely because I now realize I asked him the 'wrong' question. Instead of probing for rationales of scientific literacy, I asked him what "the goals of science education are"? To my initial query he responded: "I think the problem is generalizing an answer to that kind of question, because there are so many different goals for so many different places and so many different cultures and so many different people. I mean from one university to another, from one country to another, … even within a [university] department."

Dr. Curtis says that scientific literacy is "<u>facility with a way of thinking about the world. A way of perceiving, learning, and understanding the world</u>." I interpret this statement to mean that scientific literacy has a Practical Individual Benefit. He also says that scientific literacy is "<u>a way of thinking and dealing intelligently as a citizen in a culture with science issues</u>." Clearly, with its references to "citizen" and "culture," this statement is a type of Practical Social Benefits rationale.

Beyond these statements of rationales for scientific literacy, Dr. Curtis spoke at length about other purposes of science education that he does not necessarily associate with scientific literacy. For example, Dr. Curtis identified the goal of producing scientists as a separate goal of science education, and one that has been somewhat in competition with scientific literacy. He said, for example, that nowadays "everyone cares about [producing more and better scientists]. But I think there's more concern about the general culture's acceptance and support of science than there is about producing scientists. I'm actually with Shamos on that. I don't think we have a shortage of scientists."

He also named "international competitiveness" as another goal of science education that differs from, yet in some ways is related to, the goals of producing scientists and scientific literacy. He was mainly referring to being "competitive in international science competitions," such as the Third International Mathematics and Science Study. He thinks that 20 years ago, competitions did not drive "day to day considerations, [and] especially, they didn't attract the press coverage that has affected science education to some extent." Nowadays "the media attention [given] to the studies has affected some of the goals of science education. And reluctantly, even without admitting it, I think we as a profession have been influenced somewhat by that. Even though I think most of us would resist that influence, I think it's there." I asked him to elaborate, and he said:

> The media [pays attention to international tests] because it's an opportunity to sell products, because anytime [they] can report failure or problems or defects that potentially affect people's livelihoods, national prestige, future welfare they can sell products because they get attention. And that's why the media attends to it. It's not for any societal purpose, for sure. But we're influenced by that as educators because our clients, our customers, our audience is influenced by the media.

So, international competition on tests has now "begun to affect people's decision-making" in science education, even though science educators realize "it's … much more complex than it's made to be in the media."

Summary. In summary, then, Dr. Curtis identified rationales that fit into the "Practical Social Benefits" and "Practical Individual Benefits domains." He sees the goal of producing more and better scientists, including getting the public to support science, as a separate goal from scientific literacy. Finally, he identified the media-driven goal of "international competitiveness" on student achievement as a separate, albeit tangentially related, goal to scientific literacy.

Dr. Dobson

"From my standpoint, when we're talking about a scientifically, technologically literate person, it is important that they can deal with real things which they find as important and which affect their living." This quote from Dr. Dobson's interview shows he believes scientific literacy provides the individual with practical, personal benefits. He says, "Too often the content of typical science seems that it is studied just because somebody discovered it, or it's in the book and you need to remember it for a test." As a more desirable alternative, Dr. Dobson promotes an understanding of technology as an important educational outcome. He says he actually agrees with Shamos on the point "that technology is closer to the real life experiences of kids. And it is possible to understand the radio and the television, and other technologies that characterize modern life." Referring to technologies during instruction also provides a way to interest the student in learning:

> Apparently everybody learns more when there's something tangible that they can see and buy into. When you stop to realize that the human made world is something all can see and feel, it is not surprising for this interest and understanding. The products of technology are produced for the benefit of the species. If it's to their benefit--air conditioning, automobiles, planes, whatever else--students can see a value in their learning that you never see in just learning some natural law.

Thus, he believes, "There's more chance that a teacher will get them to really understanding nature because they need to understand something from the world of the technology than the other way around."

Shamos (1995) says that rationales used to promote the need for scientific literacy are actually better arguments for technologic literacy. Apparently, Shamos sees science and technology as separate entities. However, Dr. Dobson believes the two are inseparable, and consequently scientific and technologic literacies are really one and the same goal. He thinks other science educators agree with this view, and in fact "this represents a major shift in our thinking since the '60s."

Being an STS advocate, it is not surprising that Dr. Dobson also attributes social benefits for scientific literacy. For example, he says that scientific literacy benefits both individuals and society in the United States "Because all people need the logic, the ability to think & decide, and to participate in a democratic society." He thinks even people in less developed nations need scientific literacy, as defined by the list of attributes compiled by NSTA (Figure 4.10), because such "features … for science literacy are human traits."

When I asked Dr. Dobson if he considered himself scientifically literate, he said, "Yes." How did he get this way? "Working on real problems." Doing so has led to "all 4 purposes of science education, p. 13 of NSES." He is referring to the 4 "goals for school science" outlined in the *National Science Education Standards* (NRC, 1996), which include educating students who are able to:

- experience the richness and excitement of knowing about and understanding the natural world;
- use appropriate scientific processes and principles in making personal decisions;
- engage intelligently in public discourse and debate about matters of scientific and technological concern; and
- increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers.

According to the *Standards*, "These goals define a scientifically literate society" (NRC, 1996, p. 13, emphasis mine). This concluding statement is interesting because 3 of the 4 goals are stated from an individual's perspective, not society's. (Only the item in the third bullet having to do with "public discourse" clearly fits into the 'social benefits' Domain of rationales in my classification scheme.) However, elsewhere the *Standards* (NRC, 1996) say:

> Scientific literacy also is of increasing importance in the workplace. More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions and solve problems. An understanding of science and the processes of science contributes in an

> essential way to these skills. Other countries are investing heavily to create scientifically literate work forces. To keep pace in global markets, the United States needs to have an equally capable citizenry. (pp. 1-2)

Thus, from the *Standards'* perspective, scientific literacy not only contributes to personal economic productivity, but to national economic productivity as well, which plainly have 'social benefits.'

In reference to Shamos's argument that the cry of scientific illiteracy is used as a slogan to get more funds for curriculum programs and research, Dr. Dobson responded, "It's a problem of definition." He sees Shamos as being "in another ball park," because his definition of scientific literacy is not what Dr. Dobson thinks of as the goal of scientific literacy.

Dr. Dobson says he was "very much a part of all the new programs that came along" in the 1960s, and that he "liked what we did during the '60s a lot." At the time, he "accepted the philosophy and the research associated with the alphabet courses K – 12. I was sold on the idea that we were going to succeed with the reforms." In retrospect, though, he now thinks "in many respects they were a drastic mistake. Because the goals were focused on attempts to get science understood and portrayed in ways it was to scientists." Given what we now "know about learning," he says he sees "that we were dead wrong":

> We almost expected students to replicate the actions and the visions provided by professional scientists. If the students say the words, or they can do the labs, and if they're dealing with the great ideas of science then they'll be scientifically literate. I think that there's all kinds of evidence that none of those programs did any of that.

He was quick to add that the experiences of the 1960s also had some benefits, for example, "we [science educators] did get to talking more with first-rate scientists. And we did get pictures of these disciplines that probably we didn't have before" by getting them the scientists to share their "visions" of the science disciplines.

Summary. Dr. Dobson believes that scientific literacy should enable the individual to "deal with real things …which affect their living," such as "the radio and the television, and other technologies that characterize modern life." Clearly this is a rationale that belongs in the Practical Individual Benefits domain. Dr. Dobson also thinks that scientific literacy helps people to "participate in a democratic society," a Practical Social Benefit. He referred me to the "purposes of science education" (NRC, 1996), which not only include rationales from the previous domains, but also states a Personal Aesthetic Benefit rationale: that school science students should "experience the richness and excitement of knowing about and understanding the natural world." According to Dr. Dobson, the "features … for science literacy are human traits," a statement of a Benefit to Humanity. Thus, Dr. Dobson gives examples of all four domains of rationales, although he clearly emphasizes the two 'practical' rationale Domains more than the 'abstract.' Dr. Dobson said that in the 1960s he supported the national curricular reforms that made school science more like real science, but now he thinks such programs were "a drastic mistake" because they only really work for the scientifically gifted and leave the majority of people largely ignorant about science and technology.

Dr. Gilbert

Dr. Gilbert said that she prefers the phrase "public understanding of science," rather than 'scientific literacy' because this latter term seems to leave out the "decision-making piece" that she thinks should be an outcome of one's education in science. She says public understanding of science has "certainly been at the core of my teaching." As a high school science teacher, she did not want "to turn [her students] into scientists." She does not "think that's appropriate as a goal." On the other hand, she does think that "we should have an appreciation for what science is, and the applications in the everyday world." She adopted the STS approach to teaching in order to interest her students more, and to find "the extensions and applications to society" that the traditional science curricula were lacking. In particular, she spoke about one "role-play scenario" that she used for several years during an ecology unit that simulated a science-related social issue. She thinks that scientific literacy not only helps one to be "aware of issues" related to science, but also empowers them to take "action" on such issues. One set of issues that she gave as an example had to do with "genetic engineering and biotechnology."

One point that Dr. Gilbert made is that public understanding of science has to include—if not focus on—adults in society, and not just on school children. She says that adults need to know science for "life skills or jobs, things like that," and that students will not seek to acquire an understanding of science if their parents and guardians do not show they value it. She added that understanding science is also beneficial from "a work-force point of view," because she believes many companies "are very concerned because they feel like the educational process is not resulting in people who can come into their companies and really hit the ground running. They have to 'train' them to do simple things". Thus, she concludes, "an adult's need to know about this public understanding of science would probably be very different from a student in a formal educational institution."

Summary. Dr. Gilbert's rationales includes both domains with a practical focus. For example, she says "public understanding of science" (her term for scientific literacy) should include help the individual's "life skills," and give them an appreciation for the "applications" of science "in the everyday world," including their "jobs." These purposes are Practical Individual Benefits. She also says there are "applications to society," such as "genetic engineering and biotechnology," which everyone should not only be "aware" of, but also capable of taking "action" on if it is in the interest of themselves or the public to do so. This "awareness to action" rationale is a Practical Social Benefit, as is the benefits from "a work-force point of view" that she mentions. Although some of Dr.

Gilbert's statements may have overtones related to the "abstract" focus of rationales, she did not make any explicit or overt statements that can easily be classified in the Benefits to Humanity and Personal Aesthetic Benefits domains. Finally, like many of the other participants, Dr. Gilbert does not believe that her job as a teacher was "to turn [her students] into scientists," so presumably she excludes the 'science pipeline' rationale from the list of purposes of the "public understanding of science" (i.e., scientific literacy.)

Summary of Participants' Rationales

The participants give a wide range of rationales for the goal of scientific literacy. However, all the purposes reviewed above seem to be classifiable into four domains: Practical Social Benefits, Practical Individual Benefits, Benefits to Humanity, and Personal Aesthetic Benefits (Table 5.2). The domains are formed from the intersection of two axes that describe the foci of rationales, i.e., a scale focus (individual or group) and a utility focus (practical or abstract). The Domains are not mutually exclusive, i.e., the individual participants can and do emphasize rationales that fit into more than one domain. In fact, 5 of the participants give rationales that fit into all 4 the Domains. The other participants do not necessarily see any of the Domains as being inappropriate as a rationale for scientific literacy, although there are some minor caveats attributed to the Practical Social Benefits by at least three participants. Specifically, Dr. Johnson says that he thinks sometimes "scientific literacy is frowned upon in our community," and gave an example of a jury for which he was not selected due to his scientific literacy. Dr. Curtis said that the media-driven goal of "international competitiveness" on student achievement (which could fit into the Practical Social Benefits domain) is a purpose of science education in its own right, and not a part of the goal of scientific literacy. Dr. Benjamin said that he is mainly concerned with education for personal development, so he did not seem to endorse Practical Social Benefits such as national security and securing the "economic position" of the United States in the world. He did, however, support the Practical Social Benefits Domain in another way, i.e., he thinks scientific literacy enables people to "take part in … an advanced, industrialized, democratic society."

Table 5.2.
The Domains of Rationales for Scientific Literacy Endorsed by the Participants.
The participants are listed in the same order as tables in Chapter 4. The dark lines divide the participants into groups according to their emphasis of the Dimensions of elements of scientific literacy. A lower case "x" indicates the participant appears to have given the Domain slightly less emphasis than another.

Participant	Practical Social Benefits	Practical Individual Benefits	Benefits to Humanity	Personal Aesthetic Benefits
Johnson		X		X
Howard	X	X	X	X
Andrews	X	X	X	X
Kellogg	X	X	X	X
Benjamin	x	X	x	X
Infeld	X	X		
Curtis	X	X		
Dobson	X	X	x	x
Gilbert	X	X		

Most of the participants explicitly spoke of the 'science pipeline' rationale as a separate and distinct purpose of science education, i.e., they do not include the development of more and better scientists as part of the impetus for the goal of scientific literacy. In fact, only Dr. Howard did not express this view. Significantly, however, Dr. Howard did not speak about the 'science pipeline' at all, thus suggesting that he, too, excludes it from the realm of rationales that support the goal of scientific literacy.

All the participants except Dr. Johnson endorse rationales from both of the 'practical' rationale Domains (Table 5.2). They put less stress on the 'abstract' rationales. More importantly, the patterns in Table 5.2 suggest that the participants' fall into three general groups when referring to rationales. Five of the participants gave rationales that support all four of the Domains, at least to some extent, so they might constitute one group. Dr. Johnson is in a group by himself, supporting two personal Domains of rationales—the Practical Individual Benefits and Personal Aesthetics Benefits. And the third group consists of Drs. Curtis, Gilbert, and Infeld, who supported practical rationales from two Domains, i.e., Practical Social Benefits and Practical Individual Benefits.

Combining the Elements and Rationales Frameworks

Identifying groups of rationales for the goal of scientific literacy is an important task in and of itself, but my main purpose is to see if the resulting groups shed any light on the diversity of elements attributed to scientific literacy discussed in Chapter 4. The dark lines in Table 5.2 divides the participants into groups by their emphasis of the Dimensions of elements of scientific literacy (see Table 4.1). It seems noteworthy that, with the exception of Drs. Dobson and Gilbert, seven of the participants would be separated into exactly the same groups when referring to the rationales that they support. That is to say, Drs. Andrews, Benjamin, Curtis, Howard, Infeld, Johnson and Kellogg fall into the same groups whether one refers to the Dimensions of elements they emphasize, or the Domains of rationales they support. The finding that most of the participants can be grouped by their views with respect to rationales as well as elements suggests that they are being self-consistent, i.e., their reasons for supporting the goal are in line with what they think the goal entails.

The remaining two participants, Drs. Dobson and Gilbert, are somewhat harder to classify. Dr. Gilbert could be considered to be in a category by herself. On the other hand, if her emphasis on elements in the Affective Dimension is ignored, then she would be grouped with Drs. Curtis, Dobson, and Infeld in Chapter 4, just as she is when her rationales are considered. In other words, only her greater emphasis on elements in the Affective Dimension separates her from Drs. Curtis, Dobson, and Infeld, and that difference does not seem sufficient to warrant separating her into her own category.

Perhaps it is not necessary to consider the Affective Dimension when classifying scientific literacy views. Taking that to be the case, I will now place Dr. Gilbert in the same group as Drs. Curtis and Infeld. Similarly, I previously grouped Dr. Dobson's view with Drs. Curtis and Infeld because of their mutual emphasis on the Procedural elements. However, Dr. Dobson gives examples of all 4 Domains of rationales, which could place him in a group with Drs. Howard, Andrews, Kellogg, and Benjamin, while Drs. Infeld and Curtis only give emphasis to the two Domains of 'practical' rationales. Nevertheless, Dr. Dobson does not give as much emphasis to the 'abstract' rationale Domains as to the practical Domains. Furthermore, his view more closely resembles Drs. Curtis and Infeld (and Dr. Gilbert's) than the others. Therefore, I maintain that Dr. Dobson's moderate emphasis on abstract rationales is not sufficient to warrant separating him into his own category. In either case, these examples illustrate that the groups I am deriving are artificially bounded and may not represent absolutely distinct views on scientific literacy. It also suggests the possibility of self-inconsistency, i.e., that an individual's view of purposes may not be fully aligned with the elements of scientific literacy that they endorse.

Combining the Dimensions of elements and Domains of rationales for scientific literacy seems to be a useful way to categorize participants' views, especially when the Affective Dimension is not included. Table 5.3 shows a matrix that I will refer to as the 'Framework for Scientific Literacy Views' derived from the intersection of 2 Dimensions and the 4 Domains. Seen in light of this table, the participants' views on scientific literacy seem to fall into three categories. Two of these Categories of Scientific Literacy Views are embedded in the third as they are diagrammed in Table 5.3, and they are designated with bold lines. It is important to remember that these three Categories are generalities, i.e., there are still some differences of opinion within any given Category.

Table 5.3.
Framework of Scientific Literacy.
The bold lines outline two of the Categories of Scientific Literacy Views. The third Category encompasses all 8 of the knowledge and ability cells. Note that the Affective Dimension is not shown because it does not seem to add useful distinctions for categorizing views.

RATIONALES / **ELEMENTS**	***Personal Aesthetic Benefits***	***Practical Individual Benefits***	***Practical Social Benefits***	***Benefits to Humanity***
Conceptual Dimension	Know the facts and principles of science for personal enrichment	Know the facts of science encountered in everyday life	Know the concepts and principles of science needed to deal with social issues	Know the principles of science that makes us human
Procedural Dimension	Able to use science to answer personal questions	Able to use science in everyday applications	Able to participate in civic responsibilities involving science	Able to use science to make humane choices and wise decisions

Category 1: Knowing Science For Personal Reasons

Dr. Johnson is in a Category by himself. He emphasizes the Conceptual Dimension of elements of scientific literacy. When compared to the rationales he supports, the Practical Individual Benefits and Personal Aesthetics Benefits, it seems that his main purpose for scientific literacy is personal. That is, both Domains of rationales he supports emphasize the ‘personal’ along the ‘scale’ focus axis. Thus, in Dr. Johnson’s view, scientific literacy means Knowing (and understanding) Science for Personal Reasons.

It is perhaps not insignificant to note that Dr. Johnson is the only participant I interviewed who might consider himself more of a scientist than a science educator, i.e., his primary responsibilities are connected to a science department rather than an education department.

Category 2: Using Science for Practical Purposes

Drs. Curtis, Infeld, Dobson, and Gilbert emphasize the Procedural Dimension of scientific literacy elements, and they support practical rationales from the two Domains along the 'utility' focus axis, i.e., Practical Social Benefits and Practical Individual Benefits. In their view, then, scientific literacy means Using Science for Practical Purposes.

Category 3: Knowing and Using Science for Practical and Abstract Purposes

Drs. Howard, Andrews, Kellogg, and Benjamin all emphasized—at least to some degree—both Conceptual and Procedural elements of scientific literacy. Their views of scientific literacy included a relatively high number of elements (from 15 to 19). In turn, they support rationales that focus on the personal, social, practical, and abstract, i.e., they endorse all four Domains of rationales for scientific literacy. Therefore, these individuals have a very broad conception of scientific literacy, which includes Knowing and Using Science for Practical and Abstract Purposes.

Other Possible Categories

A number of other possible combinations of the Dimensions and Domains are conceivable, but did not appear in the data analyzed here. For example, there might be categories such as Knowing Science for Social Reasons, Using Science for Abstract Purposes, Knowing Science for Practical Reasons, and Using Science for Personal Purposes. It will be important not to exclude these (and other) possible categories from consideration. For one thing, the number of participants in this study is relatively small, and I do not intend for the results to be construed as comprehensive and conclusive. Secondly, an analysis of views extant in the literature may turn up some of the potential categories named above. And finally, what a person means by scientific literacy may depend on the context. That is, a person's definition could (appear to) change when given a different situation to think about, such as what scientific literacy would look like in a developing country as opposed to the United States.

Summary of Chapter

The goal of scientific literacy is a common theme for science education in the United States, especially at the K-12 level (Bybee, 1997). The main question that this chapter addresses is, 'Why?' That is, "What purposes do the participants (university science educators) ascribe to the goal of scientific literacy?" The intent of answering this question was to determine whether different rationales emphasized by the participants help explain their diverse views on the elements to include in 'scientific literacy.'

The rationales the participants gave for the goal of scientific literacy for all can be grouped into at least 4 Domains: Practical Social Benefits of Science, Practical Individual Benefits of Science, Benefits to Humanity, Personal Aesthetic Benefits. When combined with the Conceptual and Procedural Dimensions of scientific literacy elements, the resulting Framework of Scientific Literacy seems to encompass the views of all 9 participants. Four of the participants' views mimic the full Framework, i.e., their views include both Dimensions and all four Domains. Accordingly, I label their view the 'Knowing and Using Science for Practical and Abstract Purposes' category. The other participants' views are sub-sets of the full model. Dr. Johnson's view is labeled the 'Knowing Science for Personal Reasons' category. The remaining participants fall into the 'Using Science for Practical Purposes' category. Other combinations of Dimensions and Domains are possible, but were not observed in the participants' data.

In the next chapter, I will summarize a Model of Views on Scientific Literacy in narrative form, and then discuss the implications of the differences in participants' views of the concept.

CHAPTER 6

IMPLICATIONS AND CONCLUSIONS

The goal of scientific literacy is commonly recognized as a major focus for science education in the United States, especially at the K-12 level. Yet without consensus on the meaning(s) of 'scientific literacy' there can be little agreement on how to work towards the goal and how to know when it has been achieved (Champagne and Lovitts, 1989; Maienschein, 1999). Using 'scientific literacy' as an undefined slogan or "buzz phrase" creates "a confusion that is useful at times because it allows people to think they agree when they really do not. Yet, hiding disagreements also keeps us from understanding how we might make things better" (Maienschein, 1999). Thus, the "vague, ill-defined" (Shamos, 1995, p. 160) nature of 'scientific literacy' may be a roadblock standing in the way of real progress in science education in the United States.

The participants in this study have diverse views on what constitutes 'scientific literacy,' but in general their views seem to fall into three categories:

- Knowing Science For Personal Reasons
- Using Science For Practical Purposes
- Knowing and Using Science for Practical and Abstract Purposes

The main goal of this chapter is to explore some of the implications of these three views for policy, programs, and practices in science education, and to make recommendations for future research and work related to scientific literacy. I will begin by summarizing the study, and then summarizing the findings in a Narrative Model of Participants' Views on Scientific Literacy.

Summary of the Study

Many science educators in the United States currently promote the goal of "scientific literacy" as the central organizing theme of their discipline (AAAS, 1993; Bybee, 1997;

NRC, 1996). However, the goal of scientific literacy is not without its critics. One of the main issues concerns the meaning of the term 'scientific literacy.' As Shamos (1995) puts it, "there is no consensus on what 'scientific literacy' means or should mean. Instead, everyone involved with science education appears to have a vague, ill-defined notion of what it should mean" (Shamos, 1995, p. 160). Many others have also commented that scientific literacy lacks a clear definition or has too many of them to be useful (Agin, 1974; Champagne and Lovitts, 1989; Hurd, 1969; Kyle, 1995; Roberts, 1983; DeBoer, 2000). Along similar lines, the rationales given to promote the goal of scientific literacy have also been criticized. For example, Atkin and Helms (1993) claim that rationales for scientific literacy have accumulated over time, but they are rarely critically examined to see if they are mutually compatible or desirable. Shamos (1995) asserts that claims to support the goal of scientific literacy lack legitimacy. He says there is little or no evidence that scientific literacy is required for individuals "to be successful in most enterprises or to lead the 'good life' generally" (Shamos, 1995, p. 98). Thus, in spite of the hundreds of publications concerning scientific literacy, Laugksch (2000) concludes that at the beginning of the 21st century there is still "a view that scientific literacy is an ill-defined and diffuse concept" (p. 71).

If 'scientific literacy' has a number of meanings and rationales, science educators may believe they are all working toward the same goal when, in fact, they are pursuing different ends. Any differences in views that exist for 'scientific literacy' could have serious repercussions for science education in general.

This study critically examines the contemporary meanings and rationales attributed to the term 'scientific literacy' among participants sampled from one group of stakeholders, namely, university science educators. I attempt to discern whether or not science educators actually mean different things by the term 'scientific literacy,' perhaps because they have different purposes in mind. In this concluding chapter, I also explore whether or not their different views on scientific literacy lead to competition for scarce time and resources in the classroom. I will conclude that this diversity of views is (or has the potential to be) hindering efforts to improve the teaching and learning of science in the United States.

The perspectives informing this study include the historical literature on reform in science education since World War II (e.g., DeBoer, 1991), the literature on scientific literacy (e.g., Bybee, 1997; Laugksch, 2000; Roberts, 1983), and the interpretive research tradition in science education (Erickson, 1986; Gallagher, 1991). I have also delved extensively into the theoretical literature on general language literacy (e.g., Anson, 1988; Bizzell, 1988; Castell and Luke, 1986; Freire and Macedo, 1994; Heath, 1986; Hirsch, 1987; Walters, Daniell and Trachsel, 1994; Wilson, 1986).

The main source of data for this study consisted of interviews with 9 university science educators who were identified (by self or others) as being "knowledgeable" about the subject of scientific literacy. It is important to note that as with any study involving a small sample size, I do not intend for the results here to be construed as fully representative of the science education community as a whole. Any hypotheses I put forth here should be viewed as tentative and limited in scope.

I interviewed each participant in person. In some cases, a second personal interview or written interview was conducted to clarify and extend their responses. The interviews were semi-open ended, and consisted mainly of indirect questions so that I could compare the internal consistency of their responses. For example, I asked them to describe a scientifically literate person they know; to tell why they consider themselves scientifically literate; and to decide whether or not they would consider Einstein to be scientifically literate today if he were to be resurrected somehow. Following the constant comparative method (Strauss and Corbin, 1990), I analyzed the data in a series of coding cycles in an attempt to inductively derive themes about science educators' views of the goal of science literacy.

Narrative Model of Participants' Views on Scientific Literacy

Scientific literacy is a complex goal that currently serves as the foundation for much of school science education in the United States. The university science educators who participated in this study hold conceptions of 'scientific literacy' that include a number of elements (i.e., attributes of the scientifically literate), and they endorse several supporting rationales for the goal. In the two sections that follow, I will first describe some commonalities in the views of the participants. Next I will discuss points on which the participants have diverse and even contradictory views.

Points on which Participants Agree

All the participants in this study agree that scientific literacy is the most important goal for science education. They view the concept of scientific literacy as being relatively complex. For example, they all include a multitude of desirable or necessary attributes for the scientifically literate person to possess. The fewest number of important attributes, or 'elements,' of scientific literacy that I coded for any of my participants is 9, and the most is 22. While the participants did cover a wide array of elements, they did not include the entire universe of possible attributes (e.g., 'knowing connections between science and art,' 'using science for entertaining guests,' etc.). In some cases, elements are most likely not included because they are not considered important, but in other cases all might agree that a characteristic is really not a part of scientific literacy. For example, it is doubtful that any of the participants would say the scientifically literate should 'hate science' (which would be an Affective element). So, while there are a number of elements of scientific literacy, the range of elements is apparently not limitless.

All the elements of scientific literacy espoused by my participants can be classified into three Dimensions, which I call the Conceptual, Procedural, and Affective Dimensions. The Conceptual Dimension includes those things that can be classified as knowledge or understandings necessary for scientific literacy. The most commonly discussed Conceptual elements include 'knowing science concepts,' and 'understanding the relationships between science and society.' The Procedural Dimension covers procedures, processes, skills, and abilities that the participants think are attributes of the scientifically literate. Procedural elements frequently mentioned by participants include the abilities to 'acquire information,' 'use science in everyday life,' 'use science for social/civic purposes,' and 'decode science communications.' The Affective Dimension comprises a range of attributes connected to emotions, such as feelings, attitudes, values, and dispositions associated with scientific literacy. 'Appreciation for science' and 'Interest in science' are the most often cited Affective elements for scientific literacy, though individually they were not as frequently endorsed as the other common elements described above.

Each of the participants seems to put much of their emphasis on only one or two Dimensions (and on only a few elements within each Dimension). Nevertheless, all of them support at least one element in each of the three Dimensions of scientific literacy views, thus I do not mean to convey the impression that they consider any of the Dimensions unimportant. Additionally, while the three Dimensions are fixtures, the participants recognize the emphasis placed on them by science educators might increase or decrease over time. A good example is the 'Conceptual' Dimension, which several participants believe is less important now than a few decades ago.

The commonly supported elements (Figure 6.1) might be thought of a 'core' of scientific literacy. However, these "common" elements actually mask a fair amount of diversity in participant views about content and emphasis. For example, while participants agree that knowing some science concepts is an important element of scientific literacy, they do not necessarily agree on exactly what science concepts need to be learned, and to what extent or depth they should be understood. Still, these commonly endorsed elements could be seen as features requisite to all programs that intend to promote scientific literacy.

Conceptual Dimension
The scientifically literate person has some knowledge and understanding of

- Science concepts
- Relationships of science and society

Procedural Dimension
The scientifically literate individual is able to

- Obtain and use information
- Apply science in everyday life
- Use science for social and civic purposes
- Understand science-related communications in the public media

Affective Dimension
The scientifically literate individual has

- An appreciation for science
- Interest in science

Figure 6.1.
Outline Of the Most Commonly Endorsed Elements Of Scientific Literacy

To a significant extent, the elements emphasized (or excluded) by participants are linked to the rationales they endorse for the goal of scientific literacy. In other words, the reasons why participants think scientific literacy is necessary or desirable significantly influences which attributes they say are required to be scientifically literate. The rationales for scientific literacy espoused by my participants can be classified into four Domains, which result from the intersection of the scale (personal or group) and utility (practical or abstract) foci of the rationales. The four rationale Domains include: Practical Individual Benefits, Practical Social Benefits, Benefits to Humanity, and Personal Aesthetic Benefits. Some of the participants endorse all four of these rationale Domains, while others endorse subsets (e.g., Practical Individual Benefits + Practical Social Benefits, or Practical Individual Benefits + Personal Aesthetic Benefits).

All the participants agree that the pursuit of scientific literacy is a separate goal from the 'science pipeline,' i.e., developing scientific talent so that the country may have an adequate supply of scientists, engineers, doctors, etc. Scientific literacy is thought of as an expression of equity, as opposed to the perceived elitist nature of the pipeline goal. The science educators I interviewed do not seem overly concerned about the quality or number of scientists we have in the country or world today. Rather, they are genuinely concerned for everyday individuals and the public. [Note: A weakness of my analysis is that I include anything that does not clearly fall into the science pipeline goal under the umbrella of scientific literacy. It is possible that the broad goals of science education could have one or more other goal (clusters) than these two alone. For example, some might wish to separate out a goal related to career awareness (Harms and Yager, 1981; Roberts, 1983).]

Participants generally view the concept of 'scientific literacy' as encompassing a continuum spanning from illiteracy to highly competent. They do not view it "typologically" (Bybee, 1997), i.e., as an 'all or nothing' situation. Perhaps only the mentally disabled or very young are considered scientifically illiterate. Thus, everyone who has a 'normally' functioning brain is scientifically literate at some level; and different individuals are scientifically literate to different degrees. (This implies that the goal of universal scientific literacy has already been accomplished to some extent!) Another way to look at this is to say that everyone is capable of becoming scientific literate to some degree.

Points on which Participants Disagree or Diverge

The most significant divergence in participants' views on scientific literacy occurs in their emphases on Dimensions of elements and Domains of rationales. Some emphasize the Conceptual Dimension, others the Procedural Dimension, and still others give nearly equal emphasis to these two Dimensions of attributes of the scientifically literate. Similarly, one participant emphasizes rationales that promote scientific literacy for personal development and application, several others endorse scientific literacy for its practical benefits, and the remainder support scientific literacy for both personal and social reasons, as well as for practical and abstract purposes.

None of the participants endorse exactly the same list of elements for scientific literacy, and in fact, most of their lists appear quite different. Of the 36 elements of scientific literacy coded from participants' interviews, more than 75% of them are endorsed by 5 or fewer of the participants, and in fact about 40% of the elements have the support of only one or two participants. In other words, in terms of gross numbers at least, participants' views on the elements of scientific literacy diverge more than converge.

In general, I did not ask participants, 'Should scientific literacy include "X" element?' because that would have been putting words in their mouths, in my opinion, and it would not reveal the elements that the participants believed to be most essential. Thus, a participant might not disagree with the inclusion of a given element, but simply failed to mention it during the interview. However, in some cases participants brought up (potential) elements and then dismissed them from consideration, e.g., Dr. Kellogg said that some people include vocabulary, but she does not consider that to be an essential aspect of scientific literacy. In fact, there is quite a bit of disagreement about a few of the non-universal elements. For example, while some participants endorse the idea that the scientifically literate should be able to "engage in inquiry" on one's own, i.e., to actually 'do' science, to a certain extent (a Procedural element), others explicitly spoke against this element and said that it had no part in deciding who is scientifically literate and who is not. Another point of contention is the degree to which it is necessary for the scientifically literate person to have an understanding of the interrelations of science, technology, or science, i.e., to have an understanding of the STS perspective.

Categories of Views on Scientific Literacy

My findings suggest that, when examined on a fine-scale level, participants' views on the elements of scientific literacy are more different than they are alike, i.e., they have very diverse views about the attributes necessary for someone to be considered scientifically literate. However, on a gross scale their conceptions of scientific literacy seem to fall into three Categories that encompass a combination of the Domains of Rationales they support, and the Dimensions of Scientific Literacy Elements they emphasize. First, there is a 'Knowing Science for Personal Reasons' Category. This category emphasizes the properties of the Conceptual Dimension of elements and a personal-scale focus of rationales for scientific literacy. A secondary emphasis on the Affective Dimension of elements of scientific literacy is also present in the one participant who holds this view. In this view, scientific literacy mainly means knowing and understanding a broad range of science concepts, including a good command of the vocabulary of science, so that one may use science in everyday life and for personal enrichment. An understanding of science includes an appreciation for its history. The scientifically literate individual is able to understand science communications in the public media, and also able to communicate science to others. This view also holds that it is important for an individual to develop an interest in science during school in order to be motivated to learn more science after formal schooling has ended (so "interest in science" is actually a subordinate element to the Conceptual Dimension).

A second Category of Views On Scientific Literacy is 'Using Science for Practical Purposes.' The properties of this Category include the Procedural Dimension of elements and a practical-utility focus of rationales for scientific literacy. A secondary emphasis on the Affective Dimension of elements is sometimes associated with this view. In this view, the scientific literate person can use science in everyday life and for social/civic purposes. To do so requires being able to acquire information about science on one's own, which in turn requires being able to decode science communications in the public media. Using science also means applying scientific “habits of mind” (Rutherford and Ahlgren, 1990). The scientifically literate person knows some of the basic concepts of science, and has an understanding of the relationships between science and society. Finally, but very importantly, the scientifically literate person has an appreciation for science, but at the same time he or she possesses an awareness (or attitude) that science should not be endorsed without question.

The third Category of Views of Scientific Literacy among the participants is the ‘Knowing and Using Science for Practical and Abstract Purposes’ Category. The properties of this Category include the Conceptual and Procedural Dimensions of elements, and four Domains of rationales, including: Practical Individual Benefits, Practical Social Benefits, Benefits to Humanity, and Personal Aesthetic Benefits. In this view, scientific literacy means knowing science concepts, as well as understanding the broad principles of science. The scientifically literate person knows something about the nature of science, e.g., that it is a process involving inquiry, and that it has limitations. An understanding of science’s relation to society is also expected. The scientifically literate person can acquire information about science on one’s own, understand science-related stories in the popular media, and perhaps be able to communicate science to others. They should be able to use science in everyday life and in participating in civic (democratic) processes. The scientifically literate person also has an appreciation for and interest in science, and a desire to “stay up to date” with science in the news. Furthermore, they should have a greater appreciation for life, nature, and humanity in general due to their scientific literacy.

There are a number of other potential Categories of Scientific Literacy Views, i.e., combinations of Dimensions of elements and Domains of rationales, that might be extant but which were not found here. It could be the small sample size and the relative uniformity of the group examined here contribute to the small number of Categories discovered. That is to say, if more university science educators were interviewed, or if members of other stakeholder groups were examined—such as the public or legislators—then other Categories of Scientific Literacy Views might become evident, such as 'Knowing Science for Social Reasons,' 'Using Science for Abstract Purposes,' etc.

Again, I think it is important to emphasize that although I am able to classify participants' views on scientific literacy into a relatively small number of Categories, I do not want to imply that there is a high degree of unanimity within a given group at the present time. This is not necessarily the case, because when their views are examined on a finer scale, they often put their emphases on different elements and rationales from one another.

It would be useful to see if science educators' views of scientific literacy match those of the public, legislators, and science teachers. If these groups do not have similar visions then they may be working at cross-purposes. My framework that combines the elements and Dimensions of the scientific literacy concept with the rationales or purposes for promoting the goal could be helpful in deciding what to look for in other groups of stakeholders. That is, applying the Framework of Scientific Literacy Views could help examine extant views and promote discussion of possible future directions to take in the pursuit of scientific literacy in the United States both within science education circles, and between different groups of stakeholders.

Implications

Comparison of Implications of the Categories

If science educators hold different views on the elements and rationales for scientific literacy, it follows that they may also disagree about the ways to achieve the goal. (Of course, it is also possible that they will agree on the means even though they have different ends in mind.) In this section, I will hypothesize some general implications for policy, programs, and practices for each of the three categories (see Table 6.1 for a summary). In terms of policy, I will focus on whether or not national/state standards and standardized testing are supported by the various viewpoints. By 'programs,' I mainly mean the focus of curricula that the view might support, and whether or not textbooks would be useful. And by 'practices,' I am referring to general instructional emphases (e.g., hands-on exploration versus lecture) and the role of the teacher in the classroom. The reader should note that I am not attempting to 'cover all the bases,' thus I do not address such issues as budgets, classroom resources and facilities, class period structure (block versus traditional), differentiation (e.g., how to address exceptional children's needs), relationships of science to other subject areas, particular instructional models (e.g., 5E model) or educational materials (e.g., commercial science kits), and technology's roles. These issues would have to be reviewed on a much finer scale than I can do based on the data I have gathered for this dissertation. Such considerations would also have to include other factors, such as individual grade level, type of school (e.g., urban versus rural), and student population.

Implications of 'Knowing Science for Personal Reasons' Category

The emphasis of the 'Knowing Science for Personal Reasons' view is on knowledge and understanding of science that can either be used in everyday life, or that the individual will find interesting and personally enriching. From a policy perspective, universal standards and benchmarks for school science are probably not necessary to promote this view of scientific literacy. Standards and benchmarks might be useful as guideposts, but they are not essential. The focus is on the individual, not the group. As Dr. Johnson views it, if we "Prepare teachers who are knowledgeable, caring and thoughtful, and they will develop [their own] high standards." The idea is that the teachers will get to know their students as individuals and help them to learn as much about science as they can. Standardized testing would only be useful insofar as it is diagnostic, i.e., its purpose is to help the individual student know where he or she stands, and how the individual school (system) is doing in reaching goals it sets for itself.

Table 6.1.
General Implications for Policy, Programs, and Practices for Each of the Three Categories of Scientific Literacy Views.

Categories	**Policies supported**	**Programs advocated**	**Practices endorsed**
Knowing Science for Personal Reasons	Universal standards useful, but not essential. Standardized testing could be individually diagnostic, and largely memory-based.	Curricula that emphasize a broad range of the concepts and principles of science. Textbooks are useful.	Teachers work with students to set individual goals based on personal needs and desires. Hands-on instruction less frequent as students mature.
Using Science for Practical Purposes	Universal standards useful. Standardized testing is performance based.	Curricula emphasize procedures more than concepts. Textbooks not necessary.	Students engaged in inquiry activities throughout schooling, especially investigating personal and social problems. Teacher is guide, not sage.
Knowing and Using Science for Practical and Abstract Purposes	Universal standards essential. Standardized testing necessary; combination of memory- and performance-based questions.	Curricula emphasize balance of breadth and depth, content and process. Textbooks are useful.	Both traditional lecture and inquiry practices encouraged, especially at the higher grade levels. Teacher is both sage and guide.

To be consistent with this category, curricula should emphasize a broad range of the concepts and principles of science, not a depth of any particular branch or topic in science. Textbooks would be helpful in this regard.

To promote ‘Knowing Science for Personal Reasons,’ younger students should regularly be engaged in hands-on explorations. However, this practice should be reduced as students progress through school and are able to handle more abstract concepts, i.e., more mature students do not necessarily need to actually experience a phenomenon first-hand, but instead can learn simply by watching, reading, and/or listening. Accordingly, it would seem that lecture (and reading of textbooks) would be the hallmarks of practices found in the senior (12^{th}) grade science classroom. Learning would be directed toward discipline-based concepts, and therefore knowledge would be acquired through the transmission of information rather than through personal discovery. Although the classroom could focus on individual student's interests, the teacher would be a lead figure in the classroom.

Implications of 'Using Science for Practical Purposes' Category

The emphasis of the 'Using Science for Practical Purposes' view is on using science either for one's everyday life or for social/civic roles. Note that some science knowledge is required in order to be able to 'use' science. Due to the emphasis on the social level, universal standards and benchmarks are probably useful to promote this view. Standardized testing would be promoted to ensure that benchmarks are being met. However, the type of testing would most likely be performance based rather than memory based, i.e., students would be asked to do things rather than answer multiple choice questions.

Curricula that promote 'Using Science for Practical Purposes' should emphasize learning science process skills, as well as decision-making and information-processing skills. Depth of understanding of the unifying principles of science is seen as more important than a breadth of knowledge of science concepts. Curricula would be problem-based, and would not necessarily be centered on the distinct science disciplines, i.e., students might be in integrated science courses, not biology, chemistry, etc. Accordingly, textbooks are not necessarily required in this view of scientific literacy. Some promoters of this view would endorse Science-Technology-Society approaches to teaching and learning.

Those who hold the 'Using Science for Practical Purposes' view would encourage self-discovery of science concepts, principles, and applications. Accordingly, students are to be engaged in inquiry, especially with regards to personal or social problems.

Since students would spend a majority of their time engaged in problem-solving, teachers would spend little time lecturing and would not be the center of attention in the classroom. Students would learn from real-life experiences and from their interactions with others—including other students—more than they would from reading books.

Implications of Category 3

I label the last category to be discussed as 'Knowing and Using Science for Practical and Abstract Purposes.' This is a broad conception of scientific literacy and a correspondingly wide range of programs and practices is necessary to promote this view. Universal standards and benchmarks are useful means of ensuring that everyone has an equal opportunity to learn meaningful science. Standardized testing would be a mixture of memory-based (multiple-choice) questions and performance-based tasks (e.g., open-ended questions).

The curricula associated with this view emphasize a balance of breadth and depth, as well as a balance of content and process. Textbooks would be useful in this regard, though problem-based units would also be valuable additions to the curriculum.

Both self-discovery and direct teacher transmission of science concepts, principles, and applications are compatible with the 'Knowing and Using Science for Practical and Abstract Purposes' view of scientific literacy. Accordingly, both traditional lecture and inquiry practices would be encouraged, especially at the higher grade levels. At times, then, the teacher would be the sole leader of the class, while at other times the teacher would be a 'guide on the side' facilitating student learning.

Overall Implications

The three views I have classified for the study participants seem to be at odds with one another. For example, Categories 1 and 2 seem to be philosophically antagonistic. That is, a person holding the 'Knowing Science for Personal Reasons' view is really pursuing a different goal than someone who advocates 'Using Science for Practical Purposes.' The first person would promote learning science concepts for individual development, and would say that scientific literacy requires a broad knowledge (and interest) in the sciences. Only if one possesses this knowledge can one hope to use it. Further, knowing science is enlightening and enjoyable, and perhaps even ennobling. On the other hand, the promoter of the 'Using Science for Practical Purposes' view endorses learning the procedures and processes of science for practical application in one's daily life and civic roles. While scientific knowledge is important in this view, it is seen as being ephemeral and somewhat impotent if one does not understand how to use it. Indeed, this view promotes learning about scientific principles in depth so they can be applied to new situations one encounters in life.

It is tempting to view the first two Categories as being subsets of 'Knowing and Using Science for Practical and Abstract Purposes' Category; or, alternatively, seeing the third category as being some sort of composite or compromise between the first two (and other possible views, as well). However, I think to do so would be misleading. None of the participants who espouse the 'Knowing and Using Science for Practical and Abstract Purposes' view explicitly (or even implicitly) state that this is some sort of composite or compromise view. They do not see 'Knowing Science For Personal Reasons' and 'Using Science for Practical Purposes' as offshoots of their broader view. Rather, members of this third group all have in mind a broad array of rationales/purposes for scientific literacy, and as a consequence they require a correspondingly broad array of elements to achieve scientific literacy.

The participants who hold the first two views I discussed would probably say that 'Knowing and Using Science for Practical and Abstract Purposes' is a self-incompatible goal, not only for the reasons given above but also because of the limits on time (and resources) for science education. There is simply not enough time to give all students both a breadth and depth of science knowledge, as well as facility with scientific processes and procedures (Shamos, 1995). Certainly, it is exactly this view of scientific literacy that is at the heart of Morris Shamos' (1995) criticisms. That is not to say, however, that these science educators agree with Shamos' proposition that the goal of scientific literacy ought to be scrubbed and replaced by "science awareness" (Shamos, 1995, p. 216). Rather, they are simply arguing for a more limited view of scientific literacy.

Conclusions

The fact that there are different views on the meaning and purposes of scientific literacy was taken as a 'given' at the start of this dissertation study, and in fact came as no surprise to my participants. That is, these experts are aware of different opinions on the subject of scientific literacy, and many discussed how their own views compared to others. They recognize that scientific literacy might mean different things in different contexts. For example, different societies (e.g., developing world countries) would most likely emphasize different aspects of scientific literacy than the United States. However, some of the participants are bothered by the diversity of views on the meaning of 'scientific literacy' to such an extent they are willing to abandon the term, but not the substance of the goal. Others are nonplussed. They recognized that the concept of scientific literacy has evolved over time, i.e., the elements and rationales for scientific literacy have changed in emphasis, if not in substance, over the years. They believe this ever-changing nature of the concept has contributed to some of the criticism that 'scientific literacy' is an "ill-defined" and "vague" concept. They believe that such publications as the *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) are now bringing more consensus to the meaning of the concept. However, it is my interpretation of the interview data that there is probably not as much consensus as the participants believe. For example, there appears to be three main Dimensions of elements for scientific literacy, one having to do with the necessary knowledge, another with the requisite skills, and a third that has to do with dispositions and values possessed by the scientifically literate. The participants did not agree on which of these Dimensions should be most emphasized, nor even on the appropriate elements to include in any of the Dimensions. Thus, when the participants feel someone else's view of scientific literacy is compatible with their own, they might be fooling themselves because they are filtering their interpretations through their own belief systems.

Participants also discussed how scientific literacy has increased in importance (centrality) as a goal for science education. They view the goal as being separate from, and perhaps in competition with, the 'science pipeline' goal, which used to be the dominant goal of science education in the 1960s and '70s. As Shannon (1962) puts it: "Education in a democracy makes two somewhat conflicting demands: to discover talent and provide opportunities to nurture that talent, and to raise the level of the average student" (p. 253). Even though the distinction between these goals is rather clear in their minds, they recognize that it is not so clear to science teachers or the general public, and this confusion has no doubt also contributed to misunderstandings about the meaning of 'scientific literacy.' While 100 percent of the public may never become scientifically literate to a high degree, most of the participants agree that working towards that goal should be the main focus of science education, especially in the pre-college schools. They feel that college is the appropriate time for students to specialize.

Participants recognize that others view scientific literacy differently from themselves, and some seemed to think that their views on scientific literacy were different enough to be considered in competition with other views, if not totally incompatible. This is especially evident among those who emphasize Procedural elements over Conceptual elements, i.e., these experts think those who view knowledge as the most important aspect of scientific literacy are actually doing a disservice to learners (and hence, the public). However, most participants seem to feel that differences in views are most often related to emphasis or degree rather than real substance or kind.

One interesting finding is that the participants usually include some aspect of science communication as an element of scientific literacy, but they are not more explicit about associating scientific literacy with literacy more generally. Sutman (1996) also noted this trend: "The fact that science literacy cannot occur outside of overall language literacy is seldom discussed by science educators" or science teachers (p. 460). Perhaps it is so obvious to the participants that one must be language literate in order to become scientifically literate that they failed to make any mention of this more general literacy during their interviews. Even so, it is really quite surprising the amount of emphasis the participants put on reading (showing scientific literacy's connection to more general literacy). The reason I say it is surprising is that there are other avenues by which one may obtain information (e.g., watching, listening), not to mention exchange information (speaking, showing). That is not to overlook the fact that many of the participants did indeed discuss more than just reading. But the most often cited element related to science communication is reading, without a doubt.

The experts generally support benchmarks and/or standards. However, one implication of my work is that until purposes and meanings of scientific literacy are clarified, developing standards to achieve scientific literacy is premature.

While these experts generally think of scientific literacy as a useful concept, they do not necessarily think of it as a specific, achievable thing. Some label the term "scientific literacy" a slogan. At least one participant prefers not to even use the term. Some think it is not really operational, or at least not a really achievable goal, although it is a desirable end to pursue.

Recommendations

It is not inconceivable that science educators will soon be called upon to publicly defend their enormous expenditures of the public's tax dollars (not to mention children's valuable school time) in the pursuit of a goal that according to some (e.g., Shamos, 1995) is not achievable or in the public's best interests. It seems only logical, given the present criticisms and state of reform in science education in the United States, that science educators should seriously examine the goal of scientific literacy so they can formulate coherent and effective policies, programs and practices for achieving it—or, so they can abandon it altogether in favor of a more desirable goal. Below, I summarize 5 recommendations that stem from my study of science educators' views on scientific literacy.

Recommendation 1

Who is considered scientifically literate (and who is illiterate) depends on how 'scientific literacy' is defined. Yet, the participants of this study appear to have widely divergent views of what constitutes 'scientific literacy,' even though all of them are university science educators in the United States and are quite familiar with the concept (or at least their version of it). Therefore, while the participants may think they are working towards a common goal, in fact they may be pursuing entirely different ends. In fact, I have shown that within the 9 participants' of this study there are at least 3 different Categories of views of what 'scientific literacy' means. If time and resources for science education were unlimited, then these views might be compatible. But time and resources for pre-college science education are in fact limited. Consequently, these university science educators appear to be espousing and working towards 3 competing goals. Thus, the differences in their views could be leading to confusion among the wider audience of science teachers, program developers, policy-makers, etc.

Given that this study is based on a small number of participants, I do not want to overly generalize. Rather, I would recommend that more studies be done to examine the views of a wider range of science teacher educators, as well as other stakeholders (e.g., science teachers), to see if the different views found among the participants of this study hold more generally, as well as to see if other views are extant.

Recommendation 2

If it is found that a diversity of views on the meaning of 'scientific literacy' exists more generally, then science educators need to decide if steps should be taken to reach consensus. Some might say that having a consensus on the meaning of 'scientific literacy' is a desirable aim, because it would directly influence such things as why we teach science, what science should be taught and to whom, and how science should be taught. I have suggested that having different views leads to competition for resources. Alternatively, some science educators may think a diversity of views on scientific literacy is actually healthy and needs to be encouraged. Some people consider a single consensus view to be too limiting and incapable of serving the range of diverse interests among school children or the public (e.g., Apple, 1992, 1993a, 1993b, 1996; Ohanian, 1999; Roberts, 1983). For example, a single consensus view of scientific literacy might imply that across the country uniform standards, instructional methods, assessment instruments, etc. should be applied. Some educators worry that national (and even state) standards erode local control over education, and therefore limit important connections between communities and their schools (Rural Challenge, 1999). These educators also fear that uniform standards require schools to adopt relatively narrow curricula and teaching methods that sever crucial linkages between students' lived experiences and rigorous academic content (see e.g., Eisner, 1995). Having a single vision of scientific literacy may in fact be license to rationalize the avoidance or even destruction of other knowledge systems that are deemed inferior (see Stanley and Brickhouse, 1994). That is, the traditions of non-dominant cultures, such as the American Indians, might be unjustly ignored or even demeaned if a single view of scientific literacy is promoted. Thus, it would behoove science educators to discuss whether or not consensus on the goals of science education is a desirable aim.

Recommendation 3

The rationales for scientific literacy seem to stand on shaky ground, in my opinion. None of my participants could cite specific evidence that scientific literacy is actually necessary for everyone, although they did give anecdotal evidence of how it might benefit particular individuals. Similarly, neither *Science For All Americans* (Rutherford and Ahlgren, 1990), nor the *National Science Education Standards* (NRC, 1996) cite direct evidence or empirical studies to back up the claim that scientific literacy is essential for everyone. Such studies would be hard to find according to Shamos (1995). Rather, my participants speak of the goal of scientific literacy in moral terms. In their view, scientific literacy is the fundamental goal of science education because it is the right thing to do, not because there is a research base showing that it actually benefits people. They seem to believe that data are not particularly important when actions can be justified by moral imperative, and therefore, the goal of scientific literacy is not subject to the strictly empirically-oriented criticisms of Shamos or anyone else. Not to detract from this value system, I submit that an educational goal can have rationales that are both morally based and empirically supported. Solely basing the "fundamental goal of science education" (Bybee, 1997) on unconfirmed assumptions seems to me to leave scientific literacy open to criticism and makes it hard to defend the goal on a practical basis. I therefore recommend that we extend the basis of our rationales for promoting scientific literacy with empirical studies. That is, we should examine what science people actually use (and misuse) in their lives, as well as what science they could make use of if they were more literate (or expert).

Recommendation 4

Classifying the 'elements' and 'rationales' helps to not only reveal differences of opinions, but also points out other possible views as well as potential gaps in the pursuit of scientific literacy. For example, I find the lack of emphasis (not to mention lack of congruence) on Affective elements among my participants very remarkable. To my mind, mere possession of knowledge and skills for scientific literacy seem impotent if the person is not inclined to use them (an Affective element). It is also hard to imagine how people (in a free society) will become scientifically literate if they are not interested in science. Furthermore, Affective elements are more enduring than elements in the other two dimensions, and correspondingly, they would seem to be more important to teach. For example, 'facts' and particular processes of science might come and go. But scientists' emphasis on dispositions such as skepticism and open-mindedness have been a part of all science methods (at least in the natural sciences) for centuries, and will likely remain part for many more years to come. Yet, in my own experience as a science teacher, I found that affective outcomes for students are rarely intentionally targeted in lessons or curricula, much less measured. That is not to say that affective elements are absent from the classroom. Indeed, as some of the participants point out, there is a distinction between using affective elements, such as appreciation and interest, as a process to promote scientific literacy, and considering interest or appreciation to be an outcome of scientific literacy. In other words, some participants do not emphasize "appreciation" and/or "interest" in their definition for scientific literacy because they see these elements as means rather than ends; or perhaps they are simply by-products (e.g., "if you learn science, then you're probably going to be sympathetic to science," as one participant put it). I am not convinced by this logic, however, and therefore I recommend that Affective elements of scientific literacy should receive a much greater emphasis than they do at present.

Recommendation 5

The participants in this study see formal education as the primary route to achieve public scientific literacy. One consequence of this view is that scientific literacy is typically measured by testing children in school—for example, the Third International Mathematics and Science Study purported to measure scientific literacy of students (Orpwood and Garden, 1998). However, my interviews revealed that some of the participants attribute their own initial interest in science as coming from outside school, and they also maintain their scientific literacy informally. In fact, it would seem that informal means of education (e.g., television broadcasts, museums, books, internet sites) are vitally important in maintaining or increasing adult scientific literacy. Thus, it is important not to define scientific literacy in terms of how much schooling one has received—because schooling is not the only means of developing scientific literacy. Yet informal science education—and, indeed, adult scientific literacy—seem to be on the 'back burner,' so to speak, and not a primary focus of the scientific literacy goal at present. People frequently display in out-of-school contexts skills and understandings related to science that are not effectively taught in the school. It could be that school science contributes little to (what is desired as) scientific literacy because such literacy is (or should be) largely community and context-based. Immersion in a culture where science is actually valued and practiced is much more likely (it would seem to me) to lead to a scientifically literate individual than the structured "break it down into bits" methods of schools. In school, many students feel little ownership over the subject, but in life their involvement and investment would naturally lead to greater degree of learning. As Wilson (1986) put it:

> Children do not, generally speaking, learn to like good music by attending classes in musical appreciation, but by being in an environment where good music is constantly played. So too with all the arts and crafts and, if more obliquely, with science, mathematics, history, and all other subjects. Children become initiated into the forms of thought by being initiated in to the forms of life that generate them. (p. 33).

Immersion, involvement, and investment in science—those are the keys to producing scientifically literate individuals. That is not to say that school science is of no use; on the contrary, it is very important if for no other reason than to provide individuals with background and exposure to a wider range of science-related material than they would normally encounter in their communities. However, if scientific literacy is only associated with formal schooling then the use of potential opportunities for developing or maintaining one's scientific literacy later in life will be overlooked or rejected. Life-long learning is a laudable goal, but it is not always promoted by traditional school instruction.

Thus, both schools and community-contexts are important. Unfortunately, science educators seem to put much more time and effort into schools than they do into community-contexts. If science educators are serious about pursuing the goal of scientific literacy, then I recommend they do much more to teach science and make science-learning opportunities available and viable outside of school settings. They should turn much more attention to such things as: decrying inaccurate portrayals of science in the media (e.g., in popular movies and television shows); pursuing more resources for informal science education venues (e.g., museums, science and nature centers); and generally lobbying against non-scientific aspects of our society (e.g., horoscopes and psychics). In short, schools cannot be solely responsible for achieving scientific literacy; rather science educators must turn their attention to the promotion of a scientific society if they wish to truly achieve universal scientific literacy.

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APPENDIX A

IN-PERSON INTERVIEW PROTOCOLS

An Early Interview Protocol

<u>Interview Talking Points For Scientific Literacy Interviews</u>

1. Demographic Information
- When did you get your Ph.D.? Where? Under whose direction?
- What was your early research about?
- Where did you go from there?

2. Characterize your current major directions of research (& practice)

3. What were the major goals of science education early in your career? In the 1960s?

4. What are the goals of science education now?

5. What is the future of science education?

6. Is it fair to characterize science literacy as a goal? (Now, or in the 1960s ...)
- How has science literacy changed (in definition and/or content) since the 1960s or the beginning of your career?
- How do you define science literacy? Comparison with others' definitions?
- Shamos says science literacy is a myth. How do you respond? Should science literacy be our goal?

7. Is it fair to characterize the science pipeline as a goal?
- How has the science pipeline goal changed since the 1960s or the beginning of your career?

8. Shamos says science awareness and appreciation should replace science literacy as our goal. How do you respond?

9. Are you goal conscious in your research and practice?

10. What is your opinion of the *National Standards* (& *Benchmarks*)?

11. Are there any questions I should have asked but different? Anything else you wish to add?

<u>Optional Points</u>

12. What do you think about Bybee's opinions on science literacy?
13. What do you think about Paul Hurd's opinions on science literacy?
14. How do STS and science literacy relate?
15. What do your international experiences tell you about science literacy or science education?
16. Tell me about your educational philosophy.
17. Why is science part of the curriculum?

A Later Interview Protocol

<u>1999 Scientific Literacy In-person Interview Protocol for A. C. Kemp's Dissertation Study</u>

Date: _______________ Participant: _________________________
Circumstances:

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1. Scientific literacy for all has been characterized as the fundamental goal of science education. Do you agree or disagree?

2. Do you personally think scientific literacy is a good or appropriate goal? Why? That is, why do people need scientific literacy? What is the purpose or rationale for this goal?

3. Scientific literacy may be an appropriate goal in the United States. But what if we were in a developing country, say in Africa or Southeast Asia? Would scientific literacy be an appropriate goal for science educators in that country?

4. Since scientific literacy has become our goal, how much progress have we made?

5. We often say that scientific literacy is a necessity for everyone. But do you know of any studies that have shown how scientific literacy benefits particular individuals or groups?

6. Please give an example of a person who is scientifically literate and why do you think this? (Please describe someone you know [other than yourself] who is scientifically literate.)

7. So, your definition of scientific literacy is ...?

8. How can you know or recognize if a person is scientifically literate?

9. How can we measure or determine someone's scientific literacy?

10. Do you consider yourself to be scientifically literate? Why or why not? (How did you get this way?)

11. How or why do some individuals become more scientifically literate than others?

12. What (internal and external) factors can affect one's state or level of scientific literacy?

13. Imagine that Einstein were somehow brought back to life, being only as knowledgeable and skilled as he was in the 1950s when he died. Would you consider the new Einstein to be scientifically literate?

14. Can you please give me your opinion of the *National Standards* and *Benchmarks* for Science Literacy (and how they might affect the goal of scientific literacy).

15. Here is a simple model of some of the elements of scientific literacy. Can you give me your opinion of how important each of these elements are:

- Knowledge
- Skills (mental and physical)
- Motivation
- Attitudes and values

16. Can you think of any important elements of scientific literacy that have not been included here?

17. Morris Shamos says that scientific literacy for all is a myth and is impossible to achieve. How do you respond to Shamos?

18. One thing Shamos accuses scientific literacy of is being a vague and ill-defined concept. Indeed, I have found that different people I interview do not always give me the same definition or description of scientific literacy. What are your feelings about such disagreement?

19. Although people do not give the same descriptions of scientific literacy, I want to look into why that might be. Part of the reason may have to do with how people define science. Can you tell me your definition of science?

20. What is your definition of technology? Is technology education part of scientific literacy?

21. Another possible reason for the differences in definition is that a person's views about scientific literacy are tied to their individual educational philosophy. Can you describe your educational philosophy to me?

22. What is the future of the goal of scientific literacy? Where are we headed with this?

23. Is there anything else you can think of that you would like to share with me about scientific literacy?

24. Background information: Current position, career development, research agenda.

APPENDIX B

WRITTEN FOLLOW-UP INTERVIEW PROTOCOL

Letter

Dear ,

I am still in the process of working on my dissertation entitled Science educators' views on the goal of scientific literacy for all. I appreciate your earlier participation in my study, and now I have another favor to ask. I intended to be in Boston to interview more people and to follow up with those that I had previously interviewed. However, our baby was born via C-section on March 22nd, and I stayed home to take care of both wife and son. (Both are doing very well, incidentally.) As a back-up plan, I am looking for volunteers to respond in writing to the interview questionnaire which follows this note.

If you have time to respond to any or all of the questions in the next 4 to 6 weeks, I would owe you a debt of gratitude that I can probably never repay. I may have asked you some of these questions before, so just respond to the ones you want to answer. Also, please change the questions to suit yourself when necessary. I realize that my questionnaire is rather long, that school is currently in session and that you are probably very busy. If you cannot or do not want to respond to the questionnaire, then please do not feel under any obligation to do so. If you have any questions or comments (or when you're ready to send back your responses) you can contact me at any of the following addresses or numbers. (I'm at home more than I'm at school these days.)

Andrew C. Kemp	(770) 483-0605
1121 Millcrest Walk	Andrew_C_Kemp@yahoo.com
Conyers, GA 30012	

or

212 Aderhold Hall	(706) 542-1763
Athens, GA 30602	fax: (706) 542-1212
akemp@coe.uga.edu	

Thanks very much,

Andy Kemp

Written Interview Questionnaire

1999 Scientific Literacy Written Interview Protocol for A. C. Kemp's Dissertation Study

Your Name: ______________________________________

Date(s): ____

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1. Scientific literacy for all has been characterized as the fundamental goal of science education. Do you agree or disagree? Please explain your response.

2. Why is scientific literacy necessary or beneficial for an individual in the United States? (Or for society?)

3. Is scientific literacy for all an appropriate goal for science educators in third world countries? Please explain your response.

4. We often hear that scientific literacy is a necessity for everyone. But do you know of any studies that have shown how scientific literacy benefits particular individuals or groups? Please tell me something about these studies.

5. Think of someone you know who is scientifically literate. Describe the characteristics of that person that makes him or her scientifically literate.

6. How can you tell someone who is not scientifically literate apart from someone who possesses some degree of scientific literacy?

7. How can we measure or determine someone's scientific literacy?

8. Do you consider yourself to be scientifically literate? Why or why not? (How did you get this way?)

9. How or why do some individuals become more scientifically literate than others?

10. Imagine that Einstein were somehow brought back to life, being only as knowledgeable and skilled as he was in the 1950s when he died. Would you consider the new Einstein to be scientifically literate? Please explain your response.

11. In relation to the goal of scientific literacy for all, please give me your opinion of the *National Standards* and *Benchmarks for Science Literacy*?

12. Morris Shamos says that scientific literacy is vague and ill-defined so that anyone can put his or her own gloss on the concept. Please respond.

13. Shamos calls scientific literacy for all a myth that is impossible to achieve. How do you respond to Shamos?

14. Shamos says that members of the general public do not believe becoming scientifically literate is necessary. Please respond. If this is true, how does it affect the achievement of the goal of scientific literacy?

15. Shamos says that not only is scientific literacy for all not necessary, that it may even be a bad thing--e.g., it will cost too much to achieve and create more scientists than the market can bear. How do you respond?

16. Shamos says that arguments used to promote the need for scientific literacy are actually better arguments for technologic literacy. How do you respond?

17. Shamos says that the goal of scientific literacy for all is a front for science educators' true goal of perpetuating their own careers and keeping the science pipeline flowing. The cry of scientific illiteracy is used as a slogan to get more funds for curriculum programs and research. How do you respond?

18. What is the future of the goal of scientific literacy? How will it change (or will it change) in the future?

19. Please look back over your responses and tell me how you define scientific literacy.

20. Is there anything else you can think of that you would like to share with me about scientific literacy?

I cannot tell you how much I appreciate your time and effort in responding to this questionnaire. I owe you one!