# Rethinking Scientific Literacy Standards

by

Daniel R. Dunlap

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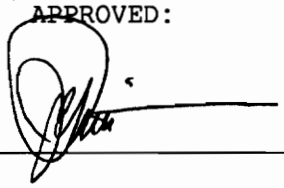

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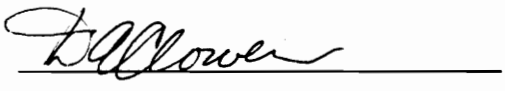

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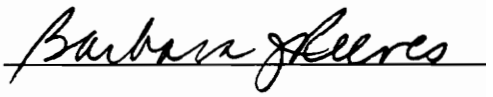

Barbara J. Reeves

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(Abstract)

This thesis explores some of the implications of contemporary science studies for current science education reforms. The scientific literacy effort proposed by Project 2061 is described and criticized with regard to its educational and philosophical commitments. It is argued that a number of controversies involving science studies can aid students and educators in learning about science, education, and society. The educational ramifications of post-Kuhnian philosophy of science, sociology of science, constructivism, and hermeneutics are discussed, and it is argued that scientific literacy needs to be reconceptualized in order to take into account the understandings and debates of contemporary science studies.

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# Introduction

The recent focus on science education reform in the public schools forces out of hiding a number of controversial issues. The rally behind standards for "science literacy" demands reflection on the question "what is the point of teaching science to *every* student?" The current effort to introduce national science standards for grades K-12 parallels in a number of ways the science education reforms of the 1960's. The current situation has been developed because of and sustained by a rash of reports in the 1980's declaring a crisis in science education, and it has culminated in a number of recent attempts to define the goals of public education and standardize the curriculum. Despite stark criticism of "top-down" approaches to curriculum reform of the 1960s and efforts to "reconceptualize" curriculum development (Apple 1982, 1986, 1990, 1992, 1993, and Pinar 1988), science curriculum reforms continue to take this traditional form. Project 2061 sponsored by the American Association for the Advancement of Science (AAAS) has taken a leading role in the current reform movement, and it is beginning to have some impact on science classrooms (see, for example, Culotta 1994, Culotta 1990, Jarcho 1995, Roeder 1995, Roeder 1994a, b, and c). The project has developed two main documents. *Benchmarks for Science Literacy* states what each student should know about science at the end of various grade levels. Project 2061 also produced *Science for All Americans* (Rutherford and Ahlgren 1990, henceforth R & A) which outlines the goals

for scientific literacy which the "benchmarks" are meant to provide a measure. So what is the main point of these goals?

In attempting to answer this question, R & A describe one of the fundamental goals of scientific literacy: understanding "the nature of science," a phrase in which none of the terms are at all problematic. However, describing "the nature of science" has been an increasingly sticky problem in science studies. Unfortunately, the schism between science education and the field of science studies (Millar 1989) may have insulated both camps from some instructive debates. For R & A the search for "the nature of science" focuses on the distinct ways of thinking and behaving that scientists exhibit in their professional work. However, recently there has been a good deal of debate in science studies over how well we can explain "science" by referring to "scientific thinking" conceived along those lines. Moreover, there is also a body of empirical research in cognitive science devoted to explaining human and scientific thinking. This debate and research can be instructive to students and educators.

The purpose of this study is to examine the goals of science literacy proposed by Project 2061, especially those which deal with the nature of science as suggested by R & A. The view of science and knowledge presented by their approach fits well with the vision for science literacy standards. However, I think that the view is contentious, so I suggest that science education standards are based on a questionable foundation. Rather, in many ways contemporary understandings of science call into question the entire project of

national standards for science literacy as they are conceived. In an attempt to engage the ongoing debates over science education reform, I will describe some of the most fundamental challenges to science literacy standards.

In Chapter One, I briefly describe some traditional approaches to curriculum development and more recent opposition that has been voiced regarding such curricular methodologies. In addition to similarities between the general approach of contemporary science education standardization efforts and the 1960s reform efforts, the general goals of the reforms are very similar. Both exemplify top-down approaches and both aim(ed) to convey a more conceptual and less factual understanding of science or "the nature of science" than perceived in the reigning curriculum. In Chapter Two, I describe some of the major criticisms of views promoted in science education circles, especially those which deal mainly with views of the nature of science. These debates can be instructive to students and teachers because they have the potential to increase our awareness of some of the major challenges that confront contemporary science studies. A number of such debates concern the specification of the role of cognitive versus social factors in explaining science, and some of these issues are taken up by R & A. Science students and educators should reflect on the ways in which different epistemological positions lead to different aims of science education. In Chapter Three, I focus on debates regarding cognitive science and constructivism as they relate to science education. I suggest that *if* the goal is to teach the nature of science and

scientific thinking, *then* this should be done in the context of contemporary science studies. R & A fail to provide an account of the contemporary view(s) in science studies which contend with their version of science literacy; thus, an enriched account of science literacy would provide a better basis for initiating and sustaining public science education reform.

# Chapter One
# Rethinking Curriculum Development

## INTRODUCTION

The history of science curriculum reform has prompted a number of science educators to ask questions like "what's wrong with the process?" (Tobias, 1992). Most of these criticisms center around problems with "top-down" reforms. R & A is meant to specify standards for scientific literacy for all students in the public schools. In this chapter, I examine the general approach of this curriculum development project, the tradition from which it emerges, and some criticisms of this tradition. In doing so, I compare this contemporary science curriculum reform to the 1960s NSF reforms. I also consider the goals of the project, some historical controversies over such goals, and the current reasons given for focusing on the nature of science and scientific thinking. This leads to a discussion in the following chapters of the role of the nature of science and scientific thinking in science education.

## TOP-DOWN APPROACHES TO CURRICULUM REFORM

Few would deny either that schools should try to achieve high standards or that it is desirable for schools to fulfill minimum standards. However, deciding on which "standards" and how to go about achieving them has always been a problem. The process used to create contemporary science curriculum standards, and what "standards" are

taken to mean in that process, conforms to an established tradition which makes certain assumptions about curriculum development, but problems with the 1960s reforms have led many educators to seriously question this tradition.

In many respects, standardization efforts have changed little since the mid-nineteenth century work of Samuel Gridley Howe who created uniform written grammar tests for Boston students (Tyack 1974 and Darling-Hammond and Snyder 1994). The legitimacy attached to "science" and "efficiency" surrounded such turn of the century efforts to centralize curriculum control and "quantify the curriculum." Task efficiency studies, systems management, Taylorism, and many other symbols of industrialism were readily adopted by early American educators. One of Franklin Bobbitt's earlier formulations of the step by step procedure or method for curriculum development characteristic of the "scientific movement" in education is found in the following principles for defining the educational process:

(I) Definite qualitative and quantitative standards must be determined for the product [students].

(II) Where the material that is acted upon by the labor processes passes through a number of progressive stages on its way from the raw material to the ultimate product, definite qualitative and quantitative standards much be determined for the product at each of these stages.

(III) Scientific Management finds the methods of procedure which are most efficient for actual service under actual conditions, and secures their use on the part of the workers [teachers].

(IV) Standard qualifications must be determined for the workers.

(V) The management must train its worker previous to service in the measure demanded by its standard qualifications....

(VI) The worker must be kept supplied with detailed instructions as to the work to be done, the standards to be reached, the methods to be employed and the appliances to be used. (Bobbitt 1913, edited from a quote which appears in Darling-Hammond and Snyder 1992, 59-60)

Bobbitt boiled down the curriculum development process to three basic steps: (1) Examine the fields of human experience, (2) break these fields into smaller and smaller (more specific) steps or actions, and (3) establish a set of competencies or abilities accordingly.

The argument is simply put: Since schools should teach something useful, simply look at what people do (that is useful to society) and break it down into teachable units. Ralph Tyler continued this tradition in the mid twentieth century by setting forth a "rationale" for developing curriculum. Tyler's *Basic Principles of Curriculum and Instruction* "attempt to explain a rationale for viewing, analyzing and interpreting the curriculum and instructional program of an educational institution" (Tyler 1949, 1).

Tyler made some additions to Bobbitt's principles, but he did not stray from the two basic steps: First, establish the goals, ends, or standards of education, and then determine how to define achievement or competency of the steps leading up to and including those ends. Both Bobbitt and Tyler had hopes that empirical studies could be of great

benefit to the curriculum process. However, in establishing such purposes, Tyler included psychological studies while Bobbitt focused on the society in terms of its vocations. Tyler also included organization of teaching experiences and the assessment of students as an explicit final steps in the curriculum development process. Tyler described his rationale as follows:

> The rationale developed here begins with identifying four fundamental questions which must be answered in developing any curriculum and plan of instruction. These are:
>
> 1. What educational purposes should the school seek to attain?
> 2. What educational experiences can be provided that are likely to attain these purposes?
> 3. How can these educational experiences be effectively organized?
> 4. How can we determine whether these purposes.are being attained? (Tyler 1949, 1)

According to this "technical tradition," the first step of the curriculum development process is to determine the *standards* or *purposes* of education. This means, simply put, that the first step is to determine what the educated student should *know* or be able to do. It is the job of the curriculum expert to state the *content* of the curriculum, that is, the knowledge that students are supposed to acquire as a result of schooling. Thus, the teaching methods or procedures which would presumably bring about such a product or output are to be determined subsequent to deciding on such purposes or content. One of the chief

features which characterizes "the technical tradition" has to do with its reliance on a given set of steps or procedures to be performed by the curriculum expert or specialist designed to precisely determine the expected outcomes of the educational process in accordance with some field of application or vocation in the society.

Project 2061 is a recent example of this type of curriculum development process. The three phases of the project closely resemble Bobbitt's and Tyler's proposals. Consider the general development procedure explicitly proposed for by R & A for developing scientific literacy standards:

> Because the work of Project 2061 is expected to span a decade or more, it has been organized into three phases.
>
> Phase I of the project has attempted to establish a conceptual base for reform by defining the knowledge, skills, and attitudes all students should acquire as a consequence of their total school experience, from kindergarten through high school. Drawing on ideas proposed by panels of prestigious scientists, mathematicians, and engineers, this book, *Science for All Americans*, is the culmination of that effort.
>
> During Phase II of Project 2061, now under way, teams of educators and scientists are transforming this report into blueprints for action....
>
> In Phase III, the project will collaborate with scientific societies, educational organizations and institutions, and other groups involved in the reform of science, mathematics, and technology education in a nationwide effort to turn Phase II blueprints into educational practice. (R & A 204-5)

This organization fits Bobbitt's principles and Tyler's rationale very well. In Phase I, the standards or purposes, that is, the knowledge, skills, and attitudes, are established. The two documents of concern here, R & A and *Benchmarks*, are intended as companion sources. The authors explain:

> *Benchmarks* **is different from a curriculum, a curriculum framework, a curriculum design, or a plan for curriculum.** It is a tool to be used by educators in designing a curriculum that makes sense to them and meets the standards for science literacy recommended in *SFAA* [R & A]. (AAAS 1993, xii)

Phase II and III of Project 2061 deal with designing and implementing effective curricula, teaching methods, or educational practices that conform to the standards. Some of the problems associated with structuring curriculum development or reform in accordance with the technical tradition have to do with this first step in curriculum development. As Fensham notes:

> The project is avowedly top-down, with scientists at the top. Even in Phase II, in which the alternative curriculum models are to be worked out, there is talk of creating 'a cadre of committed knowledgeable and experienced leaders' to translate the recommendations of Phase I into actual curricula and to act as 'experts in school curriculum reform' (Fensham 1992, 800)[1]

As in the technical tradition, the initial purpose of the curriculum making process for Project 2061 is to produce those

statements which represent certain competencies or "standards" that the experts or scientists deem appropriate. In reporting on a recent speech made by the director of project 2061, James Rutherford, Jarcho remarks that

> Reforms are often spoken of as "top down" or "bottom up," and Rutherford argued that we need both. From the top we need vision, standards, and consensus. Otherwise, we will just be muddling around. (Jarcho 1995)

Standards here are a set of minimum competencies or "thresholds" which are meant to be used to judge whether or not a student is "scientifically literate" (*Benchmarks*, xiii). They are a set of statements which are proposed to assess universally scientific literacy: who has it and who does not. For Project 2061, the authority on what is *essential* to "science literacy" rests with engineers, scientists, and mathematicians. They are the experts who are best equipped to describe the statements of the universal knowledge that "we" want *all* students to know (AAAS 1993, 303). However, this "top-down" or "technical" approach to curriculum development came under severe criticism following the 1960s reforms.

*Reconceptualization of Curriculum*

During the 1970s, opposition to traditional curriculum theory was developed by a group commonly referred to as "the reconceptualists" (Pinar 1988). Several of the major features which

bound the group together were (1) a strong dissatisfaction with "the Tyler rationale," (2) a loss of confidence in the value of curriculum workers to teachers, and (3) a concern that the curriculum was under the control of technologists, test makers, textbook publishers, and school administrators (Lincoln 1992, Jackson 1980, and 1992b). The authors who stand out as the leaders of this group are Michael Apple and William Pinar (Pinar 1988, Eisner 1992).

One of Apple's (1990) main concerns is with the distribution and control of curricular knowledge. Rather than viewing curriculum in terms of the "management and control ideology" represented by the Tyler rationale, Apple argues that "curriculum" should be seen as an agent which contributes to the existing economic and social conditions. He cites Bowles and Gintis (1976), Bernstein (1977), and Bordieu and Passeron (1977). Accordingly, the individual's underlying perception of the social order provides the locus of understanding (Apple 1990). Certain knowledge, skills, language, or behavior is deemed of high value to the extent that certain competencies act much like money or capital. Thus, such high status knowledge, skills, language and behavior are referred to as having "cultural capital" or representing "symbolic property." It is this highly valued knowledge, e.g., scientific skills, that schools as well as the larger society distribute unevenly. Through this control of the distribution of knowledge, curriculum functions to maintain the cultural and economical stratification that exists in the society. Because of the greater access of the dominant or middle class culture to the high value knowledge or competencies, the economic or

social order is reproduced by the curriculum. In other words, the curriculum simply perpetuates the existing social divisions.

Crucial to this argument is the notion that the curriculum serves *both* to categorize students according to specific abilities (and/or "dis-abilities")*and* to legitimate these categories. Considering curriculum knowledge as "capital," the phrase "it takes money to make money" is analogous to saying that "the curriculum rewards those with a predisposition to its standards", and these standards will tend to reflect those values of the dominant or middle class.

As a solution, Apple (1990) suggested that educators consider alternative models of systems management such as in open and biological systems, but, he admits that "there are no easy alternatives to a management and control ideology" (121). Apple provides several examples, mostly inner city schools, where "progress" has been made. He explains the significance of these examples:

> Together, these examples say something very important about the politics of curriculum and teaching. In each case, success required the conscious building of coalitions between the school system and the communities being served. In none of the cases was the impetus generated from the top. Rather, bottom-up movements, within groups of teachers, the community, social activists, and so on, provided the driving force for change. Finally, none of these instances were guided simply by a technical vision. Instead, each is overtly linked to a political project: enhancing democracy at the grass roots, empowering individuals who had heretofore been largely silenced, creating new ways of linking people outside and inside of the schools together so that schooling is not seen as an

> alien institution but something that is integrally linked to the political, cultural, and economic experiences of people in their daily lives. (Apple 1993, 40-41)

Thus, Apple is very critical of the Tyler rationale and top-down approaches which explicitly centralize curriculum control. The dangers of such top-down approaches to curricular development for reconceptualists like Apple stem from the control of curricular content by a central or dominant group. Apple warns about science education's role in the alleged increasing domination by economic interests on education:

> Even though the sciences may deserve an important and enhanced place in the curriculum, it is crucial that educators situate reforms in science education in the larger social context in which educational reforms are taking place. How and by whom *reform* is defined and carried out will have a significant impact on who benefits from the process. I argue that education in general has increasingly become dominated by economic interests that can lead not to enhancing equality, but to its opposite. There are important ideological shifts that are occurring not only in what education is for, but in the content and control of curriculum and teaching. This has also been accompanied by an attempt to not only increase the influence of economic needs on schools, but to make education itself an economic product like all others. This will have a major impact on science education in particular, because both science and technology are seen as high-status in the transformation of education into solely an economic tool. (Apple 1992, 779)

The relation of economics to science education is certainly complex and includes a wide range of issues from those dealing with advertising to

students to those the pressure on schools to fill the work force demands. The main criticism of top-down approaches concerns the ability of a controlling group to impose its economic interests, values, ideologies, world view or goals on the general public under the guise of universally legitimate or objective truth. This criticism extends to the very first step: Establishing the goals.

## THE AIMS OF CURRICULUM

A number of writers have noted the tension between two major types of educational goals or "orientations" to curriculum development. Spring (1994) refers to "public" versus "private" goals. Jackson (1992b) refers to a number of different orientations, but he notes the historic division between those advocating "social reform" and "individual development." Klopfer and Champagne (1990), in their attempt to derive lessons from the 1960s reforms, contrasts the "professionalist" and the "visionary." For Montgomery (1994) it is "Academism" and "Practicalism," and Cuban (1990), in attempting to explain why education reforms appear again and again, also refers to "this enduring curricular tension between values embedded in academic and practical subjects" (5). Spring (1991) suggests that the intellectual goals, which are taken to be the number-one goals of teachers and parents, conflict with the public goals which are used to justify the establishment and maintenance of public schools. Before describing how R & A propose to meet the challenge of these diverse

goals, I will show how they attempt to serve both orientations or sets of goals.

*The Social Reform Tradition*

R & A write: "America's future--its ability to create a truly just society, to sustain its economic vitality, and to remain secure in a world torn by hostilities--depends more than ever on the character and quality of the education that the nation provides for all of its children" (v). The basic argument has changed little since it was articulated by Bobbitt earlier in this century. As Jackson (1992b) puts it, "The ultimate source of the school's curriculum for Bobbitt turns out have been the society at large. He believed the school's job was to rectify the deficiencies of knowledge and skill that result from society's oversight or malfunctioning."

In the 1980s several reports declaring educational crisis were published. The seminal document of this period is *A Nation at Risk: The Imperative for Educational Reform, 1983* prepared by the U.S. Department of Education's National Commission on Excellence in Education. This report spells out several common themes of education reforms. Most notable is the connection between the nation's declining international economic and industrial competitiveness and the declining quality of the nation's educational system.

> Our Nation is at risk. Our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world. This report is

concerned with only one of the many causes and dimensions of the problem, but it is the one that undergirds American prosperity, security, and civility. We report to the American people that while we can take justifiable pride in what our schools and colleges have historically accomplished and contributed to the United States and the well-being of its people, 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 a people. (NCEE 1983)

R & A echo these same concerns, but they fail to provide any other argument or research to support the claim to a causal connection between curriculum standardization and economic recovery. Nevertheless, the connection is clearly made in the following passage:

> The necessity for strengthening science education in the United States has been widely acknowledged in the numerous education studies conducted in the 1980s....
>
> Most of the education reports of the 1980s have been motivated by the confluence of two different growing public concerns. One concern is America's seeming economic decline. Our domestic affluence and international power--both based substantially on our scientific and technological preeminence--have been weakening in relation to those of other countries, especially Japan. The other concern consists of certain trends in U.S. public education: low test scores, students' avoidance of science and mathematics, low learning and being ranked near the bottom in international studies of students' knowledge of science and mathematics. (R & A, 195-6)

Tanner and Tanner (1990) have discussed problems with the reasoning used in these "conflicting reports," and a number of writers have warned about an over reliance on standardized test scores (Frechtling 1989, Apple 1990). Montgomery is particularly critical of Project 2061 in this regard:

> Scores on standardized tests are invoked as the revelation of two sad "truths": first, the entire nation is failing in leadership; second, that nearly *everything* is wrong with the American school system. The basis for such a remarkable leap of supposition is, however, never given, let alone subjected to inquiry--and this in a book that argues the great need for "critical thinking" while impugning "the learnings of answers more than the exploration of questions."
>
> Faith in test performance as a kind of scientific indicator for widespread conditions, like faith in the "scientific attitude" as a solution to all human problems, represents the applied positivism that has surrounded so much of American schooling in this century. Indeed, as a basis for critique, test performance becomes itself a technical argument for exactly the type of education that has been universally decried for over a generation, that is, education-as-test-preparation, as memorization, as recitation, as mechanical process in general. (Montgomery 1994, 261)

While Montgomery identifies problems with assessing educational performance, what is of more concern here are the reasons given by R & A for thinking that scientific literacy standards are the answer to economic and social ills.

The 1960s "crisis" in education was influenced largely by "professionalists" who considered the goals of science education to be mainly directed at preparing students for future advanced study and careers in natural and applied sciences (Klopfer and Champagne 1990). Among more recent documents expressing concerns about future shortages of scientists and engineers, the United States Congress's Office of Technology Assessment (OTA) reported in 1988 that "shortages of scientists and engineers are not inevitable; the labor market will continue to adjust, albeit with transitory and perhaps costly shortages and surpluses." This document goes on to suggest that the government may need to take a more active role in recruiting and retaining "flexible talent for the work force" as well as ensuring that women and minorities are provided opportunities to participate in science education (OTA 1988, 1). Thus, the main appeal here of a more inclusive science is the perceived future need for more scientists and engineers.

However, the science literacy efforts are intended for *all* students, especially the students who are *not* headed for careers in science and engineering. So the question is, why do these students need to know science? R & A provide an argument for the nation's need for science literacy, but first it helps to consider other reasons given for science education reform and what they mean by "scientific literacy."

*The Individual Development Tradition*

The contrasting views of John Dewey and Franklin Bobbitt illustrate the marked division between advocates for social reform and

advocates for individual development of students. Jackson describes these differences:

> Both men were advocates of reform, but when it came to specifying the changes that should be made, they diverged markedly. Dewey focused principally on the psychological nature of the learner. He believed that teachers should begin their curriculum planning with those psychological considerations in mind. Bobbitt was more concerned with social conditions outside the school. He called for detailed studies of those conditions to identify what needed to be taught. (Jackson 1992b, 14)

Dewey is perhaps the most renowned opponent of the "science movement" which is associated with a number of early twentieth century efforts to apply technical and efficiency measures to education; however, science plays an essential role in Dewey's thought. He emphasized the individual development of the child or "child centered" inquiry. Dewey's philosophy of science and his educational theory held together well. His instrumentalist philosophy of science was connected to his child centered perspective on education. Briefly put, Dewey argued that education must be consistent with the continuity of the child's experience. In other words, it should connect past, present, and future experiences of the child. Developing curriculum, for Dewey, is not simply a matter of determining occupational demands. Rather, it is matter of determining student needs and experience. For Dewey, education was not necessarily a means to other ends. The learning experience could be an end in itself, that is, it was not purely or

fundamentally for some future application. Rather, optimally, it was to be part of the meaningful experience of the present. As Dewey explained:

> When preparation is made the controlling end, then the potentialities of the present are sacrificed to a supposititious future. When this happens, the actual preparation for the future is missed or distorted. The ideal of using the present simply to get ready for the future contradicts itself. It omits, and even shuts out, the very conditions by which a person can be prepared for his future." (Dewey 1938a, 29)

Without actively engaging the student in the (present) learning process in a way which is consistent with (past) experiences, there can be no learning or (future) preparation. Thus, Dewey's emphasis is on the student's individual background, thinking, and personal fulfillment rather than (or, more properly, as a prerequisite to) future professional preparation.

R & A claim similar goals though the emphasis is still on preparation and future achievement:

> Education has no higher purpose than preparing people to lead personally fulfilling and responsible lives. For its part, science education--meaning education in science, mathematics, and technology--should help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. (R & A, v)

So we see two main foci or rationale for the creation of scientific literacy standards. First, the nation's economic strength and social integrity are connected to the quality of education and especially the public's understanding and respect for science. Second, science education is deemed valuable to the individual's own personal development. Scientific literacy standards are proposed as if they were the long awaited answer to these goals. In order to explain why scientific literacy standards are given such esteem, it helps to consider what is meant by "scientific literacy."

## SCIENCE AND LITERACY

Two questions need to be answered by the proponents of science literacy: What is meant by "science," and what is meant by "literacy"? One of the most general assumptions of Project 2061 is "less is better." However, in the attempt to reduce the amount of content in general science curricula, it is necessary to concentrate on some aspects of science education so as to allow for teachers to eliminate other less important details. Thus, answering the these two questions is crucial to providing a rationale for science literacy efforts. In Chapter Two, I will draw out Project 2061's answer to the question "what is science," and, in Chapter Three, I will address questions regarding "literacy." But first, I will consider the emphasis on reducing the amount of science content and the problems this goal engenders.

The "fundamental premise" of Rutherford and Ahlgren's (1990) recommendations is that schools need to "focus on what is essential to scientific literacy" (ix). This means understanding key concepts and principles of science and using scientific ways of thinking for individual and social purposes (ix). Much of the concern of the 1960s reforms also centered on teaching a more "conceptual" and less "factual" science.

For example, the Physical Science Study Committee (PSSC) in 1956 focused attention away from the product of science or facts, and toward the "processes" of science. Jerome Bruner's Biological Sciences Curriculum Project (BSCS) 1959 emphasized "structure and fundamental principles" of the discipline. Bruner argued that the best way to "maximize transfer of training" was through the understanding of these principles. But there are two huge problems with this. First, it was realized fairly early on in the study of these 1960's reforms that the variables which correlated significantly with the degree of student achievement of the goals went far beyond the assumption that common curricula beget common results. As Darling-Hammond and Snyder put it:

> First came the discovery that teachers' curriculum transmissions were so varied as to negate the concept of a common curriculum... Then came the finding...that teachers' values, classroom behaviors, and the resulting social learning climate in the classrooms were strongly related to students' achievement and attitudes....
> Finally, researchers discovered that the process of curriculum implementation and school change was itself a set of complex

> variables strongly influencing outcomes. (Darling-Hammond and Snyder 1992, 63)[2]

However, an equally, if not more, crucial problem has to do with the formulation of the "structural or fundamental principles" of the scientific disciplines. Tanner and Tanner describe the problems such attempts met:

> First, most subjects had nothing resembling a single structure or organizing principle. Even in fields such as physics and mathematics, there was little if any agreement among university scholars on a single structure. Organizing principles change in accord with one's purpose in studying a given subject. Thus the idea of structure was a fiction. (Tanner and Tanner 1990, 178)

This passage suggests that one of the main problems with attempting to focus on "concepts" or "structure" rather than the particular and more numerous "facts" is that there are a variety of conceptual structures from which to choose. In other words, there is no single "core" set of concepts of science on which educators agree. The 1960s reforms proposed moving away from emphasizing particular facts and toward focusing on some set of key concepts such as "the processes" or "structures" of science. The particular (and in many ways very similar) focus of R & A is on "scientific literacy." In order to understand the implications of this focus for R & A, it is helpful to get an idea of what they take to be essential to explaining science. This appears to be a top priority for the project. In the order of recommendations,

describing what all students should know about "the nature of science" is first in line.

## CONCLUSION

Like the 1960s reforms, Project 2061 represents a top-down curriculum reform. However, since the sixties, a tradition of criticism of this approach to curriculum development has emerged. A major basis of these criticisms concerns the danger of imposing a group's values, world view, or ideology on the schools. Such charges have been directed specifically at science literacy reforms. For example, Kyle states that,

> in my view, the scientific literacy for all students theme continues to be shrouded in an ideology preoccupied with traditional authority, cultural uniformity, and technocratic accountability of students and teachers, thereby delimiting the acquisition of a narrow interpretation of scientific literacy to the "haves" and further isolating such elitist populations from the social and cultural "have nots". (Kyle 1991, 404)

Many of the science curriculum reforms of the 1960s aimed to focus on a more "conceptual" and less "factual" science education. R & A echo this concern, and, as such, they pay a great deal of attention to "the nature of science" for which "scientific thinking" is fundamental. Scientific thinking, habits of mind, or inquiry are submitted by R & A for their public benefits since they presumedly allow people to consider and solve social and technical problems appropriately, and they are also submitted

for their private benefits since they presumedly allow people to think appropriately for themselves.

This view of scientific literacy assumes two things: First, it assumes a prescription for human thinking. In other words, it assumes that people should think in certain ways. Second, it assumes that "scientific thinking" is fundamental to the nature of science. However, there has been a good deal of discourse and debate in science studies concerning the nature of science especially as it pertains to scientific thinking. There has also been recent research in the field of cognitive science that is relevant to these questions. In the next chapter, I will describe Project 2061's view of "the nature of science" and some of the controversies which such a view involves especially with regard to science education. I suggest that the relations between views on the nature of science and views on science education need to be closely examined. In Chapter Three I will turn to what I take to be some of the most salient implications for science literacy which can be drawn from contemporary science studies. These involve learning from controversies in science studies concerning contemporary or "postmodern" fields such as hermeneutics, constructivism, and cognitive science.

# Chapter 2
# Rethinking the Nature of Science Education

## INTRODUCTION

There has been a great deal of attention given to the relation between philosophy of science and science education. It is commonly expressed in terms of the question "What can philosophy of science *offer* science education?" However, the question can be turned around to ask "how philosophical stances pertaining to science determine educational objectives." In other words, there are two ways to look at the role of philosophical positions in science education. (1) How do history, philosophy, and sociology of science *fit into* the goals of education, and (2) to what extent do they *determine* the goals of education?

R & A provide a rationale for focusing the nature of science:

> Our fundamental premise is that the schools do not need to be asked to teach more and more content, but rather to focus on what is essential to scientific literacy and to teach it more effectively. Accordingly, *Science for All Americans* [sic] recommendations for a common core of learning are limited to the ideas and skills having the greatest scientific and educational significance for scientific literacy. (R & A, ix)

With this as a guiding premise, the very first chapter of the recommendations covers the nature of science (in ten pages). However,

to a large extent, these recommendations ignore some well established critiques and suggestions concerning history and philosophy of science in public science education. A number of these critiques call for a greater role for history, philosophy, and/or sociology of science in science education. As such, both scientific literacy and these critiques deal with question (1) above. However, the philosophical position one takes can have serious ramifications for one's views on science education, and so one should also ask question (2). We shall see how the realist-instrumentalist debate and Dewey's instrumentalist/naturalist philosophy of education deal with the connection between philosophical concerns and educational goals. Contemporary debates in science studies over the role of social and cognitive explanations of science also illustrate concerns and tensions which are instructive. In this chapter, I will outline the main issues involved in these debates and some of their connections to science education. I suggest that the view to which Project 2061 ascribes is one sided, and it ignores a variety of views which run counter to or criticize many of the assumptions about science made by R & A. However, the questions raised by such opposing views often entail a skepticism regarding value of science literacy standards as they are offered. Before examining the criticisms of history, philosophy, and sociology of science presented in traditional science curricula, I will first describe some of the key assumptions about the nature of science proposed by R & A.

## THE NATURE OF SCIENCE

Chapter One of R & A is titled "The Nature of Science". This chapter is divided into three sections: The Scientific World View, where the authors describe the "basic beliefs and attitudes" that scientists share about their work; Scientific Inquiry, where they attempt to describe the features of science which distinguish it as a mode of inquiry; and The Scientific Enterprise, where the individual, social and institutional dimensions of science enter into the description of the nature of science.

Matthews (1994) has clearly laid out ten major theses advanced in the first chapter of R & A. These are as follows: Realism, fallibilism, durability, rationalism, antimethodism, demarcationism, predictability, objectivity, moderate externalism, and ethics (Matthews 1994, 37-40). Matthews quickly notes that "on just about every point listed above, philosophers, historians and sociologists of science will be aware of a body of contending literature" (Matthews 1994, 40). In order to describe the general view and opposition to it, some of the ten theses described by Matthews can be grouped together. There are two basic sides here. First, fallibilism, antimethodism, moderate externalism, and ethics directly reflect a degree of opposition to positivistic philosophy of science. On the other hand, realism, durability, rationalism, demarcationism, predictability, and objectivity reflect more positivistic tendencies.

While R & A promote a retreat from the view of *absolutism*, that is, the view that science can provide absolute knowledge, they

nevertheless cling to a strong form of *realism* and *antirelativism*. For example, they state:

> Scientists assume that even if there is no way to secure complete and absolute truth, increasingly accurate approximations can be made to account for the world and how it works (R & A, 4).

This suggests that scientists are *convergent realists*, that is, they believe that scientific theories are converging on reality or getting closer and closer to "the truth." No argument for this claim is given.

This strong version of scientific realism commonly goes hand in hand with forms of rationalism, demarcationism, objectivity and predictability. The following four passages from R & A state their position with respect to these matters:

> 1) Although all sorts of imagination and thought may be used in coming up with hypotheses and theories, sooner or later scientific arguments must conform to the principles of logical reasoning--that is, to testing the validity of arguments by applying certain criteria of inference, demonstration, and common sense. (R & A, 6)

While this passage indicates that R & A deny a strict logic of discovery or inductive method, that is, they posit a form of *antimethodism*, the passage also suggests that they uphold a *rational* method of justification. Exactly what these criteria of inference for testing the validity of arguments actually consist of is not spelled out by R & A; nevertheless, they maintain that there are special characteristics that all science exhibits.

2) There is simply no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge. There are, however, certain features of science that give it a distinctive character as a mode of inquiry.... Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypothesis and theories, the kinds of logic used, and much more. (R & A, 5)

This passage proposes that science can be *demarcated* from other activities. "This is a contentious and debated matter" (Matthews 1994, 38). What is fundamental to the view presented by R & A is the promotion of some privileged status or epistemic authority of science that comes from scientists' striving for objective or external means for determining truth. Strong versions of realism and correspondence theories of meaning often regard observations as objective means for deciding on truth of the world. R & A promote a similar status for observations in the following passage:

3) Sooner or later, the validity of scientific claims is settled by referring to observations of phenomena. (R & A, 5)

Again in the next passage, R & A emphasize the priority of observations in science, but they go on to propose a further characteristic of science, *predictability*:

4) The essence of science is validation by observation. But it is not enough for scientific theories to fit only the observations that are already known. Theories should also fit additional

observations that were not used in formulating the theories in the first place; that is theories should have predictive power" (R & A, 7)

These claims probably sound familiar to those who have studied logical empiricist philosophy of science popular about fifty years ago. These philosophers focused their efforts to a large extent on justifying the claims, methods, and reasoning of scientists. For example, Carnap (1950) attempted to develop a logic which justified in terms of probability the inductive claims made by scientific laws and theories. However, logical empiricists were pressed to justify (empirically or otherwise) the truth or acceptance of such logical systems. "Observations" were to act as the foundation on which to ground theories to the world. But it was soon realized (perhaps even before the fact in Duhem 1914) that scientific observations were inextricably intertwined or "laden" with theory. In other words, one of the main challenges to empiricist justifications of scientific laws and theories is that "*observations* are theory-infected" (Morick 1980). This understanding of observations requires careful consideration of claims like those made in passages 3) and 4) above. While few logical empiricists would deny the general role of observations in settling scientific claims, they discovered very early on that the emphasis on observations, especially when observations are wrongly assumed to be objective and theory independent, really does not get us very far in *justifying* scientific laws and theories. More is needed than logical reasoning even in simply justifying (not to mention discovering) scientific laws and theories.

Contemporary science studies and sociology of scientific knowledge have added a number of challenges to the logical empiricist's focus on observations as a means of justifying scientific claims. For example, Pickering (1984) argues that the decision to "end" or conclude an experiment is *arbitrary* with respect to the experimental observations. This suggests that observations are not sufficient grounds for justifying experimental conclusions as passage 2) implies. Galison (1987) provides an in-depth response to Pickering's suggestions that experiments are chosen to *fit* the theories at hand, so the ending of an experiment is *arbitrarily* decided. Galison finds three problems with Pickering's view. First is the assumption that experimenters are *logically* compelled to accept their experimental conclusions, that is that they are *constrained* by logic. Galison claims that this is not so. The second problem with Pickering's view, according to Galison, is that interest theory, the view that scientists are driven to their actions or decisions by their class or economic *interests*[3], exaggerates the flexibility of theory. Rather, Galison argues that mathematical and physical theory *does* provide significant constraints on scientists or experimenters. Third, interest theorists ignore the constraints that experiments and techniques place on the users because these theorists tend to focus too much on what *theories* do rather than what experimenters do.

Thus, in his work *How Experiments End*, Galison attempts to answer accusations that experimental results totally underdetermine scientific decisions to commit to experimental claims. However, in doing so he

challenges the strict dichotomy between discovery and justification. This view is then troublesome to the claims made in passages 1 and 3 above. R & A suggest there that regardless of how claims are brought up or *discovered*, what matters in the end is the ability to *justify* the claims in accordance with logical arguments and scientific observations. But such a strict division between discovery and justification is questionable even in the responses to arguments which challenge views that assume a crucial role for experimental results in the resolution of scientific claims. In addition, the demarcation criterion suggested by these passages (especially 2) entails some very serious shortcomings. For example, are there activities which we may not wish to call scientific, like astrology, alchemy, or witchcraft, that also, much like astronomy, chemistry, and psychology, use logic, hypotheses, theories, and evidence?

In addition to problems distinguishing criteria of justification and reasoning used by scientists, there are problems with the requirement that theories be *predictive* of observations not already known as claimed by passage 4 above (see for example, Mayo 1995, Giere 1983, Lakatos 1978, Musgrave 1974). R & A also make claims about the *ethics* and *norms* of scientists which are said to have strong influences on what science is.

The section titled "The Scientific Enterprise" presents a normative view of science which has much in common with the tradition associated with Robert Merton in the sociology of science. Merton

(1942) formulated four "sets of institutional imperatives" or norms of science--universalism, communism, disinterestedness, and organized skepticism (270). R & A propose a similar view.

> Most scientists conduct themselves according to the ethical norms of science. The strongly held traditions of accurate recordkeeping, openness, and replication, buttressed by the critical review of one's work by peers, serve to keep the vast majority of scientists well within the bounds of ethical professional behavior. Sometimes, however, the pressure to get credit for being the first to publish an idea or observation leads some scientists to withhold information or even falsify their findings. Such a violation of the very nature of science impedes science. When discovered, it is strongly condemned by the scientific community and the agencies that fund research. (R & A, 11)

"Openness" corresponds to the norm of communism. As Merton explained: "Secrecy is the antithesis of this norm; full and open communication its enactment" (Merton 1942, 274). "Critical peer review" suggests the norm of organized skepticism or the "temporary suspension of judgment and the detached scrutiny of beliefs in terms of empirical and logical criteria" (Merton 1942, 277). "Accurate record keeping" suggests objectivity or disinterestedness, and "replication", arguably, suggests the norm of universalism. These norms or attitudes basically represent tendencies for scientists to behave in certain ways, so they are also empirical claims. However, the distinction should be made here between the claim that scientists indeed *do* behave in these ways and the

claim that scientists *should* behave in these ways. The distinction is usually given in terms of the difference between "description" and "prescription."

R & A appear to be arguing both. Scientific thinking or *inquiry*, in a sense, acts independently of social influences, but the enterprise of science, for example the direction of research funding, does not. Scientific ways of thinking are autonomous, universal, or in accord with a priori principles. The "social" influences on and in "the scientific enterprise" do not ultimately enter into the production or justification of scientific knowledge which constitutes "scientific inquiry." Thus, scientists, if they are to be successful in their work, think in certain ways, and, in fact, they also act according to certain norms.

In sum, scientific literacy, for R & A, resides in the understanding and use of "scientific inquiry" and the acquisition of "scientific habits of mind." Scientific inquiry refers to the ways of thinking that scientists employ in their work. These include certain ways of validating hypotheses through observations of phenomena, forming logical arguments, striving for objectivity, and judging of theories according to their explanatory power (R & A, 5-9, 172). Scientific habits of mind include not only these ways of thinking and skills but also certain values and attitudes. These values and attitudes, which are manifest in the "work" of scientists (as opposed to their inquiry or thinking), refer to the socially derived values which influence the

direction of research, the dissemination of knowledge, the norms, and the ethics involved in the application of research (R & A, 9-12, 173).

Scientific habits of mind are given particular importance because of their potential to contribute to the critical and independent thinking of citizens as well as their potential to solve social and technical problems (R & A, vi-vii, 171-183). The "habits of mind" proposed by R & A sound remarkably like the "traits of mind" proposed by Conant (1945). "Traits of mind" consisted not only of attributes like effective thinking and communication, those attributes most commonly associated with traditional views of scientific reasoning, but also those which deal with making relevant judgments and discriminating among values, attributes usually associated with the humanities. Conant was concerned with providing life skills for general students, and high standards were reserved for the more able student (Conant 1945). Montgomery criticizes Conant's view: "The scheme seemed to be a compromise, but is was more a ploy, aimed from the top down at the age-old separation of classes through a partitioning of means, in this case access to knowledge in a modern society" (Montgomery 1994, 206).

R & A are ultimately concerned with promoting values and attitudes about science and technology, but they emphasize "thinking skills" (175) and "thinking scientifically" (5). These exemplary ways of thinking and acting constitute the "the nature of science" for R & A. Particular ways of observing, thinking, experimenting, and validating "represent a fundamental aspect of the nature of science and reflect how science tends to differ from other modes of knowing" (3). It is this

view of the nature of science that makes up much of the concepts fundamental to the characterization of scientific literacy in R & A. However, there has been a considerable amount of criticism of science education for adhering to outdated philosophy of science.

## PHILOSOPHY OF SCIENCE AND SCIENCE EDUCATION

There is a rich variety of criticism of the history and philosophy of science in school science education (to name a few, Matthews 1989 a and b, Macmillan and Garrison 1984, Garrison and Bentley 1990, Duschl 1990, Griesemer 1985, as well as *Journal of Research in Science Teaching* vol. 29 no. 4). Selley has compiled a list of the topics that have appeared repeatedly in the history and philosophy of science literature for teachers:

1. overt discussion of the nature of scientific investigation and the status of the resultant knowledge;
2. reference to the tentative status of theoretical statements, especially in the context of "unobservable" entities such as molecules, genes, or electromagnetic waves;
3. presentation of the falsification argument, that it is a better test of a proposition to seek to refute it, than to verify it;
4. presentation of the constructivist argument, that theories and models are human inventions or ideas, and not discoveries of pre-existing truth;
5. some allusion to the sociology of knowledge, especially an increased emphasis on the role of the scientific community (as opposed to the lone researcher) in the establishing of the body of accepted (= true) knowledge;

6. the use of case studies from the history of science to illustrate the importance of the social context of the scientific enterprise, or to exemplify theory change (Kuhnian "revolutions");
7. as a consequence of the recognition of the value of plural or alternative models in science, greater opportunity for students to consider two or more different explanations of the same phenomenon, and in some cases to appraise them for intelligibility and usefulness. (Selley 1989, 24)

These concerns center around the role of philosophy, history, and social studies of science in learning science. A number of these discussions concern inadequacies of the philosophical views of science presented by science curricula. Others have suggested causes for the failure of modern courses to teach the nature of science. These causes include: "Teachers' own inadequate views about the nature of science" and a "degree of confusion in the philosophical stance implicit in many contemporary science curricula" (Hodson 1988). This confusion is in some ways excusable given the diversity of views concerning the nature of science.

A number of philosophers of science and science educators have suggested curriculum reforms which require or at least allow a greater role for philosophical, historical, and sociological analyses than in the existing curriculum. Chief among these suggestions is a call for less of a "subject" oriented science curriculum and a request for one which integrates history, philosophy, and sociology of science into the science curriculum as well as science teacher training (Bybee et al.

1991, Duschl 1990, Pitt 1990, Jordan 1989, Manuel 1986, and Sloep and van der Steen 1988). While these integrative approaches emphasize humanities and social sciences, other integrative approaches emphasize "application" and technology. Some versions of Science, Technology and Society (STS) education exemplify this latter approach.

While the label "STS" has many uses (see Cheek 1992), in the context of school science education it usually includes a greater role for applications to social and technical problems and hands-on or everyday experience in teaching science. A number of educators have discussed the prospects and vision of STS approaches (Yager et al. 1992, McFadden 1991, Waks and Barchi 1992, Zoller et al. 1990). Rutherford (1988) even enlists STS goals for Project 2061. However, the extreme diversity of these approaches reflects the lack of agreement concerning philosophical matters.

Several academic quarrels illustrate the degree to which philosophical positions entail ramifications for science education. One example of opposition between philosophical positions arising in the context of educational reform is the realist-instrumentalist debate between Mach and Planck, which took place in Germany around the turn of the century. Rather than being a debate fought purely in the context of philosophy of science, Fuller (1994) argues that this debate extended significantly to the context of science pedagogy.

*Mach Versus Planck on Science Education*

Around the turn of the century, the German Reich's educational system was undergoing reform, and, in the process, a controversy arose regarding the aims of secondary science education. Two major concerns emerged regarding these matters: increasing educational opportunities for citizens and introducing credentials for the selection and sorting of the future workers. As Fuller explains:

> Most parties agreed that some form of (natural) science education should be made available in at least some of these schools -- but in what form, and to what end? Answers to these questions turned on what was taken to be the distinctive epistemic contribution of the natural sciences, and its relevance to the "modern" German citizen who may not pursue scientific research as a career, but whose continued support would be needed for science to continue at its current pace. (Fuller 1994, 202)

The two rival philosophical positions defended by Mach and Planck would turn out to be crucial to the educational imperatives they would prescribe. Mach joined George Berkeley in rejecting realism. For Mach, scientific laws and theories simply allowed a more economical use of thought or labor. Ultimately science saved time and effort by summarizing specific facts. Theories and laws were, so to speak, *tools* for doing work. Thus the goal or value of science was to summarize the greatest number of facts with the least amount of thought. Mach's instrumentalism had a direct bearing on his views on science education.

Basically science was appropriate to the general population (non-scientists) only insofar as they could use it or assimilate it into

their daily lives. Given this view, Mach was understandably guarded against giving too much authority to science. Only when the speculations of scientists were linked to specific applications, should they be taught. For Mach, there was no reason to *indoctrinate* students into the scientific mindset, but for Planck there was.

Planck, like many realists, regarded science as providing an increasingly accurate picture of the world. This concurs with the view presented by R & A: "Scientists assume that even if there is no way to secure complete and absolute truth, increasingly accurate approximations can be made to account for the world and how it works" (R & A, 4). Scientific problem-solving, for Planck, was capable of improving any field. This led Planck to the view that students should be trained in the esoteric aspects of science which make it distinctive. For Planck, in order to sustain public support for science and recruit and prepare the next generation of scientists, some of the theoretical structure and content had to be taught.

These two views had very different implications for science education. "Mach's instrumentalism drove him to see mass empowerment and scientific credentialism as incompatible goals for education, whereas Planck's realism led him to endorse credentialism as a necessary complement to a rapidly expanding educational system" (Fuller 1994). Mach was largely concerned with citizens' obtaining what was most useful to them. This was a consequence of the instrumentalist view which was also held by John Dewey.

*Dewey's Instrumentalism and Naturalistic Philosophy*

Dewey (1938b) distanced himself from realist philosophies and drew important parallels between philosophy and education. His instrumentalist views on science were intimately related to his philosophy of education. He rejected a priori intuitions and arguments from "pure Reason" that typically characterize realist arguments. Realists commonly claim that sensations, observations, and intuitions, even prior to any particular instances, provide proof of our access to the real world. In the following passage, Dewey displayed his disdain for *a priori* philosophy:

> Philosophy is frequently presented as the systematic endeavor to obtain knowledge of what is called Ultimate and Eternal Reality. Many thinkers have defended this conception of its guidance only by means of ideals and standards that have their source in Ultimate Reality. On the other hand, skepticism about the worth of philosophy usually rests upon denial of the possibility of attaining such knowledge (Dewey 1938b, 255).

Again, later in the same paper, Dewey claimed,

> The issue of the relation of knowledge to experience is strikingly raised by the two opposed philosophies of education. According to one of them, knowledge is a final end in itself and nothing has a right to the name of 'knowledge' (in its full sense) unless it is attained by a faculty of reason and rational intuition supposed to be independent of experience (Dewey 1938b, 266).

He firmly believed that philosophy and education were inextricably related.

> Indeed, it would be difficult to find a single important problem of general philosophic inquiry that does not come to a burning focus in matters of the determination of the proper subject matter of studies, the choice of methods of teaching, and the problem of the social organization and administration of the schools (Dewey 1938b, 260).

His own instrumentalist and naturalist philosophy led him to have distinct views about the purposes of education.

For Dewey, like Mach, science education was fit for the student only in so far as it connected with the student's own experiences. Specifically, for Dewey, this meant that proper education should be "continuous" with the past, present, and future experiences, and that it be an *interaction* between external and internal conditions of experience. Important to his view was the notion that some knowledge was worth learning for its own sake. In other words, learning should not be viewed purely in terms of its contribution to some future vocation. Rather, the learning process itself should be worthwhile, just as simply *making* a tool can be fun. It is this notion of the present experience of the student that Dewey claimed was not attended to by the "old" education. Rather, preparation for some future work is often proposed as *the* purpose of education. Dewey adamantly rejected the vocational preparation ideology: "When preparation is made the controlling end, then the potentialities of the present are sacrificed to a supposititious future" (1938a, 29). The student's present experience in the learning process and its continuity with past experience were fundamental to determining learning goals. Standards state learning goals, and for Dewey students do not, and in some senses

cannot, automatically adopt universal sets of learning goals. As Dewey argued:

> the field of experience is very wide and it varies in its contents from place to place and from time to time. A single course of study for all progressive schools is out of the question; it would mean abandoning the fundamental principle of connection with life-experiences (Dewey 1938a, 52).

Thus, Dewey's instrumentalism drove him to see the purposes of education in terms of the individual student's own means and ends. Since there is no ultimate set of truths or epistemological foundation or objective reality, there are no *core* principles (of science) which hold their value for everyone everywhere. There are only *tools* to be found, made, used, and discarded. This instrumental view which he promoted had much in common with his naturalistic view of education.

Dewey often urged educators to appeal to experience and experimental method in their work. However, for Dewey, science or experimental method did not consist of a fundamentally distinct kind of thinking or reasoning. Rather, scientific method simply represented formalized common-sense. Dewey made this point quite clearly in the following passage:

> Stated in other words, the scientific method is not confined to those who are called scientists. The body of knowledge and ideas which is the product of the work of the latter is the fruit of a method which is followed by the wider body of persons who deal intelligently and openly with the objects and energies of the common environment. In its specialized sense, science is an

> elaboration, often a highly technical one, of everyday operations. In spite of the technicality of its language and procedures, its genuine meaning can be understood only if its connection with attitudes and procedures which are capable of being used by all persons who act intelligently is borne in mind. (Dewey, 1938c, 271-272)

Again, learning, including the learning of science, relies on the connection with everyday experiences, because, for Dewey, science is *continuous* with common sense. Hence, learning science, that is, learning how to formalize common sense thinking, has a practical and direct relation to everyday life. Scientific ways of thinking are perfectly natural.

Therefore, learning science, and learning in general, should be construed in terms of *natural* operations. Scientific behavior, then, consists of natural responses of humans to some natural environment as with any usual human practice. In the context of education, this *naturalistic* emphasis meshed well with Dewey's instrumental views. Both suggested considerations of continuity between past and present experience. For Dewey (1916), "instrumentalism means a behavioristic theory of thinking and knowing....the operations of knowing are (or are artfully derived from) natural responses of the organism" (14). This is why his view is referred to as "organic" or "naturalistic." However, Dewey, very early on, dismissed the kind of reductionist behaviorism associated with Skinner (1953) which suggested that psychology needs to be reduced to observable behaviors.[4] Rather, for Dewey, *inference*, a process that strict behaviorists might find troublesome, belongs in the

same category as other human practices like "plowing." "It is a matter of hands-on operations, of those practices that occupy us in society" (Garrison 1990, 198). Thus, for Dewey, a naturalistic approach entails the treatment of human thinking and human practices as natural phenomena and rejects reliance on a priori and monistic rules.

Evers (1987) and Walker and Evers (1984) suggest an approach which retains Dewey's naturalism but rejects his instrumentalism in favor of a type of realism. However, this is inconsistent with Dewey's own views. Evers (1987), like most realists, ultimately seeks determinate connections between sentences and the world, in other words, some version of the correspondence theory of truth. In terms of ontology, this means that the objects of knowledge are the objects of the world. The goal of inquiry for realists is some ultimate knowledge or truth about the world. But for Dewey (1916), "the object of knowledge" is something which the processes of inquiry *produce*, and so ontology depends on specific kinds of practice. As Garrison puts it:

> Ontology, objects of knowledge, is originally the product of concrete operations performed upon existential material and conditions by skilled practitioners who transform the metaphysical possibilities into actualities, that is to say, they make meanings. Change the operations, alter the transformations, transform the practice, and the objects of knowledge, the ontology of inquiry that logic itself depends on, alters also. This is the "Epistemology Naturalized," the "Ontological Relativity" of Quine's "Natural Kinds" --only better. (Garrison 1990, 197).

As Garrison observes, Quine (1969) praises Dewey's behavioral approach to language and notes that it preceded the later Wittgenstein's similar view. Nevertheless, the point of promoting a naturalistic philosophy in the context of science education is to argue that learning, including learning in and about science, must be seen as empirical or natural phenomena or processes of humans.

Siegel (1993) suggests that science students can benefit directly from the study of the philosophical controversy concerning naturalism. This is consistent with Dewey's view regarding the dialectical unity of opposites in experience which reflects his Hegelian roots. In Chapter Three, I suggest some research that might aid students in such a naturalistic study of science, but now I turn to two other examples where philosophical and social considerations of science have implications for science education: Kuhn and the Sociology of Knowledge.

*Kuhn, Exemplars, and Science Education*

In *The Structure of Scientific Revolutions*, which was first published in 1962 and has since become one of the most prominent and controversial works in science studies, Kuhn presented a view that challenged a number of well accepted assumptions about scientific change. History shows, according to Kuhn, that science can be divided into two phases. What most scientists do most of the time is solve problems under a paradigm. *Normal science*, then is basically *puzzle-solving.* A paradigm, accordingly, represents a *guide* for a group's

research which supplies exemplars, phenomenal worlds, theories, or problems for a group of scientists. Prior to the emergence of a paradigm, the choice of problems, range of theories, and acceptable approaches are far more arbitrary than when puzzle-solving takes place under a paradigm.

In pre-paradigmatic science, there is no one standard to guide the selection of research problems as in normal science. There are no central or exemplary problems on which scientists may focus. The paradigm identifies a few "acute" problem solutions or significant facts, and the paradigm allows certain connections of theories with facts or theoretical predictions. It also allows for the articulation of theory for example by specifying constants. What binds the group to the paradigm is the acceptance of certain applications or examples as models for future research. In sum, Kuhn proposes that normal science is puzzle-solving according to a paradigm where a paradigm basically offers a set of criteria for choosing a problem. The later account of paradigm deals more specifically with relations among exemplars or solved problems. It is the shared examples of successful practice which constitute a paradigm for Kuhn (1974).

Paradigm change or scientific revolution exhibits a number of features which are not characteristic of normal science, and these features set Kuhn's view apart from previous views of scientific change. Most notably among those features is the idea that paradigm change means knowledge is not cumulative. The old theories or paradigms are not strictly deducible from the new and vice versa. For example, some "non-

theoretical" assumptions need to be made in order to get Newton's Laws from Relativity Theory. Thus, Newton is not strictly deducible from Einstein. More to the point, the emergence of a new paradigm in a revolution calls for the rejection of the old one, and the acceptance of a new paradigm by scientists involves a kind of conversion experience.

Paradigm shift is a change in worldview which requires that the scientists must be re-educated. The increasing reliance on textbooks or their equivalent always accompanies new paradigm emergence. However, these textbooks "disguise" the revolution. That is, they make the dramatic paradigm shift or "revolution" appear gradual and continuous rather than sudden and discontinuous. Textbooks basically play the role of explicating the shared examples, exemplars, or solved problems, which the group is committed to by way of the paradigm. The later writings of Kuhn are more explicit about a paradigm's being the shared similarity and dissimilarity relations among exemplars. It is the family resemblances of the features of solved problems which constitute the paradigm. Becoming a member of the community means internalizing the shared similarity and dissimilarity relations between exemplars. In other words, being a member means having the ability to use the categories of solved problems consistently with other members of the community.

Given that a paradigm consists in the communities' shared similarity and dissimilarity relations between exemplars, what then is paradigm change? For Kuhn, the phenomenal worlds change after a revolution. Phenomenal worlds are neither purely subjective nor

objective. Rather, they have both subject-sided and object-sided moments (Hoyningen-Huene 1993, 65). This allows for differences among member concepts without admitting to absolute relativism. In terms of cognitive frame theory, two people may be able to identify the examples of categories consistently though they may be using different (possibly overlapping) features to make the classification. Kuhn (1974) uses the concept "duck" as an example. While individuals agree on examples of ducks, some look at their neck size and feather colors while others look at their feet color and bill shape; all may look at the feet shape (webbed). Moreover, some features are *better* examples of features of a duck (like webbed feet) than others (like brown eyes); that is, concepts show a *graded structure*. As we will see in Chapter Three, Kuhn's view involves treating scientific concepts in a manner that is consistent with research in cognitive science.

What, then, are the implications for science education? Given Kuhn's view, science education consists mainly in the learning of similarity and dissimilarity relations among exemplars. Exemplars are solved problems. Physics education may represent a pluperfect case where traditionally the objectives have centered around learning *how* to solve certain kinds of problems. For example Chi et al. (1981) suggested that becoming an expert in physics consists of learning how to categorize problem types according to certain principles, like the conservation of energy, used to solve the problems.

One of the roles of science education is fairly clear within this view. Science education orients upcoming members of the community. It disseminates the paradigms. It does this by teaching the similarity and dissimilarity relations among exemplars or solved problems. However, this view says little about what the general student should get out of science education, and it is questionable whether it accounts for the diversity of subject matter commonly thought to be part of good school science curriculum. Nevertheless, Kuhn's view makes certain claims about the role of education in science. It initiates members into a paradigm, but such membership is not arbitrary and mystical. Rather such membership is determinable in cognitive/behavioral ways. Thus, Kuhn's view is consistent with a naturalistic approach.

While Kuhn may be the most influential figure in science studies, his views are also quite controversial. Kuhn's *The Structure of Scientific Revolutions* is often interpreted as suggesting that paradigm change or revolution is an irrational process. This interpretation may be popular because it suggests that one should look for alternative non-cognitive explanations of scientific change such as those given by fields like sociology. If scientific change is irrational, it is reasoned, then perhaps we can find non-rational explanations. Thus, many of the arguments offered by sociologists of science flourished, but these generally came from a sociological tradition quite distinct from the logical empiricist tradition in the philosophy of science which Kuhn destabilized.

## SOCIOLOGY OF SCIENTIFIC KNOWLEDGE AND SCIENCE EDUCATION

Rather than concentrating on the cognitive dimensions of science that were commonly associated with scientific knowledge, Merton (1942), in attempting to empirically study the purely institutional and behavioral aspects of science, focused on the "normative" characteristics of science. He described the "ethos" of science in terms of certain values shared by scientists: Universalism, communism, disinterestedness, and organized skepticism. These were meant to be purely social, so they were not meant as claims about scientific thinking or knowledge. However, the scientific habits of mind promoted by R & A include both Mertonian norms and rationalistic ways of thinking. Scientists, according to R & A, think in certain ways, and they also behave in certain ways beyond purely rational thinking. Violation of the ethical norms of science is a violation of the very nature of science, for R & A; thus, these norms function as prescriptions in the strongest sense of the term. That is, they describe *proper* behavior of scientists. Learning science then, even for the general student, requires the internalization of "scientific habits of mind."

Recently sociologists have diverted their attention away from the study of the cognitive activity and products of science like reasoning, rationality, and truth. Rather, they focus more on the observable behavior or social "practices" of science. A central tenet which many contemporaries adhere to in science studies and in science education is "science is socially constructed." The Sociology of Scientific

Knowledge (SSK) stands out as the prime example of a social constructivist approach. Chief among the concerns of SSK is the total rejection of a priori arguments concerning the nature or essence of science. As Pickering describes this movement:

> [SSK] differentiated itself from contemporary positions in the philosophy and sociology of science in two ways. First, as its name proclaimed, SSK insisted that science was interestingly and constitutively social all the way into its technical core: scientific knowledge itself had to be understood as a social product. Second, SSK was determinedly empirical and naturalistic. Just how scientific knowledge was social was to be explored through studies of real science, past and present. (Pickering 1992, 1)

Pickering (1992) goes on to describe differences between the "microsocial" and "macrosocial" approaches to SSK, but he also notes their "shared refusal of philosophical apriorism coupled with a sensitivity to the social dimensions of science" (2). The macrosocial approach focuses on the "interests" of groups and their relation to scientific knowledge content. The micro-social approach focuses on, for example, describing the outcome of controversies as the result of "negotiations" between "actors." Latour (1987) describes these outcomes as "black-boxes" which are normally not open to question but which can be opened to reveal the controversies. The variety of SSK approaches are linked by these kinds of emphases on social studies of science and naturalistic study of science.

Contrary to Kuhn, and a number of contemporary thinkers in Science Studies, Latour and Woolgar (1986) distance themselves from cognitive studies of science by calling for (perhaps a jestful) ten-year moratorium on cognitive explanations of science. However, this moratorium will soon be over, and furthermore DeMay (1992) has even suggested that Latour himself has already been developing a cognitive approach to science under the guise of a science of representation. This may be seen in Latour's (1987) focus on "inscriptions" which are "immutable" and "mobiles." These inscriptions act like mental representations and so contain some suggestion for a role for cognitive activities.

In any event, a number of proponents of SSK are considering the implications of SSK-like approaches for science education. For example, Bruffee argues that there is a discrepancy between the way scientists do and teach science. "According to this [SSK] alternative, science is not a methodical evidentiary process but a process of interpretive construction" (Bruffee 1992, 20). He maintains that science education should focus on the conversation and collaboration of scientists and science students. Students "should be learning to 'talk science' with each other and 'write science' to each other" (Bruffee 1992, 21; see also Bruffee 1993). Though Bruffee points out some pedagogical concerns, the most explicit attempt to draw recommendations for science education from SSK comes directly from two leaders of the strong programme in SSK.

Harry Collins and Trevor Pinch recently produced a book titled *The Golem: What Everyone Should Know About Science* (Collins and Pinch 1993). Rather than specifying a set of educational objectives or standards, the book supplies seven case studies in the history of science. Each of these studies is meant to convey the "untidiness" of science rather than its adherence to a logic method of discovery. The authors explain the purpose of the book:

> *The Golem* presents a view of science as fallible and untidy, a matter of craft rather than logic. To do this it examines a series of experiments, some famous, such as the proofs of relativity theory, and some not so famous. In each case it shows that scientific certainties do not come from experimental method, but from the way ambiguous results were interpreted. (Collins and Pinch 1993, i)

For Collins and Pinch, a golem is a metaphor for science. A golem is a mythical bumbling giant which will follow orders but is unaware both of its own strength and of its ineptitude.

> The idea of this book is to explain the golem that is science. We aim to show that it is not an evil creature but it is a little daft. Golem Science is not to be blamed for its mistakes; they are our mistakes. A golem cannot be blamed for doing its best. But we must not expect too much. A golem, powerful though it is, is the creature of our art and our craft. (Collins and Pinch 1993, 2).

Clearly these sociologists have a significantly different view of science than R & A. One of the most outstanding points of dissent

between the two views concerns the role of experiments in resolving scientific controversy. As discussed earlier in this chapter, the extreme position in SSK, usually represented by adherents to the strong programme, holds that experiments cannot be the ultimate arbiters in scientific disputes because experiments are not *conclusive* until they are *concluded*, and deciding when to conclude or end the experiment requires deciding when the results are conclusive. This "circle" is what Collins and Pinch call the "experimenter's regress." They explain:

> Experimental work can only be used as a *test* if some way is found of breaking into the circle of the experimenter's regress. In most science the circle is broken because the appropriate range of outcomes is known at the outset. This provides a universally agreed criterion of experimental quality. Where such a clear criterion is not available, the experimenter's regress can only be avoided by finding some other means of defining the quality of an experiment; and the criterion must be independent of the output of the experiment itself. (Collins and Pinch 1993, 98)

The ability of experimental results to arbitrate among competing experimental claims is at the root of the disagreement between R & A and the strong program. Realists, here represented by R & A, emphasize the rational methods and content of science curriculum since these methods and concepts allow us to deliberate over the truth. Thus, everyone's life can benefit from science content and methods. The strong programme in SSK, here represented by Collins and Pinch, de-emphasize content and

method as much as possible. Rather, they suggest that the public needs to understand the politics of science.

> We agree with the public understanders that the citizen needs to be informed enough to vote on technical issues, but the information needed is not about the content of science; it is about the relationship of experts to politicians, to the media, and to the rest of us. (Collins and Pinch 1993, 145)

One point of focusing on the negotiations and agreements and politics of science rather than content and methods is to show that science is neither perfect nor worthless, but much the same as other human activities. Thus, the knowledge that the average *citizen* should know about science is knowledge about how to deal with humans, especially experts.

> scientists are neither Gods nor Charlatans; they are merely experts, like every other expert on the political stage. They have, of course, their special area of expertise, the physical world, but their knowledge is no more immaculate than that of economists, health policy makers, police officers, legal advocates, weather forecasters, travel agents, car mechanics, or plumbers. The expertise that *we* need to deal with them is the well-developed expertise of everyday life (Collins and Pinch 1993, 145)

Scientists, then, should be treated as any other experts, with no special access to reality.

> To change the public understanding of the political role of science and technology is the most important purpose of our book and that is why most of our chapters have revealed the inner workings of science.(Collins and Pinch 1993, 145)

In this regard, one of the recommendations they make for science education concerns the ability of classroom science to act as a "microcosm of frontier science." Teachers and students should reflect on the diverse lab results commonly obtained in school science which allegedly lend support to a stable hypothesis and the reinterpretation of the local effects of the lab apparatus and sources of error. As they explain:

> That ten minutes renegotiation of what really happened is the important thing. If only, now and again, teachers and their classes would pause to reflect on that ten minutes they could learn most of what there is to know about the sociology of science. For that ten minutes illustrates better the tricks of professional frontier science than any university or commercial laboratory with its well-ordered predictable results. (Collins and Pinch 1993, 151)

This suggests one main source contention among the views of R & A and SSK. R & A want to focus on the ways in which scientists achieve consensus despite the fallibility of science. On the other hand, Collins and Pinch claim that the understanding disagreements among scientists provides more of a basis for what the general public needs to know about science.

## CONCLUSION

Philosophy of science in public school science education has been greatly criticized for its adherence to outdated ways of understanding science and, in particular, the nature of science. Many contemporary educators suggest that more attention needs to be given to history, philosophy, and sociology of science, but the question is *which* views and in what capacity? While commonly the question that is asked is "what is the role of philosophy of science within the goals of science education," the problem can be turned around to ask "how philosophical positions determine goals of science education." The Mach-Planck debate, Kuhn's view of scientific concepts, and the Sociology of Scientific Knowledge (SSK) all illustrate various roles which philosophical views can play in specifying recommendations for science education.

R & A present a call for scientific literacy standards which take as an important goal teaching the nature of science, scientific inquiry and scientific habits of mind. However, there are competing explanations of science which entail quite distinct recommendations for science education from those proposed by R & A. Many of the discrepancies can be understood in terms of educational implications which arise from differences between realist and anti-realist positions. Realists generally want to explain the consensus regarding and reliability of scientific knowledge by resorting to its representativeness of the world. Anti-realists, on the other hand, tend to focus on the contingent nature of even the most fundamental

scientific claims including, for example, observations. While instrumentalists like Mach and Dewey only saw the value of science education to the general society in its connection with common thinking, realists like Matthews (1994) continue to claim that "scientific thinking is not natural thinking" (Matthews 1994, 28). One of the main issues in the debates boils down to a question of the degree to which scientific knowledge is *constructed* and the degree to which it is *discovered*. This is at the crux of much of the debate over the goals of science education.

In the next chapter, questions concerning the transmission and reproduction of scientific knowledge in education are directed at these issues. Scientific literacy standards represent a proliferation of one set of answers to these questions, but the answers provided by this approach are contentious in the contemporary setting.

This contention suggests that there are a number of themes in the science education reform literature which need further explication. One of the most conspicuous of the current themes is *literacy*, and another is *constructivism*. Scientific *literacy* usually takes the role of indicating some kind of deficiency in the public's current understanding of science and ability to communicate and deliberate productively over scientific and technological matters. The public is scientifically *illiterate*, and so education needs to insure that students become scientifically *literate*. But what does this mean? In order to begin to answer this question, one should have some ideas about the transmission and reproduction of scientific knowledge. In the naive version, science

produces knowledge, and education disseminates or transmits it. However, at the center of many of the educational concerns regarding transmission and reproduction lie questions about *interpretation.* This is the realm of *hermeneutics,* and this realm extends to include a number of the concerns central to contemporary science studies and the recent focus on "postmodern" education (Doll 1993, Aronowitz and Giroux 1991). One of the issues to which discussion of hermeneutics in the next chapter leads back is constructivism. In the current science education literature, a great deal of attention is given to constructivism, but there is a diversity of opinion over which form of constructivism should be accepted and what exactly the various forms mean to science education. The two main strands of constructivism correspond to the tension addressed earlier in this section. While *cognitive* or *psychological* (Matthews 1994, 138) *constructivism* draws heavily from developmental psychology, *social constructivism* draws from the social study of science. In the next chapter, I will consider the implications of *literacy* in light of controversies regarding constructivism and cognitive science. This includes introduction of the tradition of philosophy known as *hermeneutics.* By considering scientific literacy in terms of these contemporary controversies, questions regarding the goals of literacy as conceived by R & A can be properly addressed.

# Chapter 3:
# Rethinking Literacy, and Standards

## INTRODUCTION

Project 2061, in promoting scientific literacy for all students, makes certain implicit and explicit assumptions about science and knowledge. In Chapter Two, I discussed what R & A take *science* to be. In this chapter, I will consider what *literacy* standards are taken to be. In doing so, I will draw from a number of diverse perspectives. Understandings and controversies which derive from constructivism, hermeneutics, and cognitive science shed light on some of the implicit and explicit assumptions of literacy standards, but such understandings often involve principles which conflict with the goals of literacy standards. While I suggest that both science educators and students can benefit from the contemporary discourse in science studies and beyond, I also suggest that many of these contemporary understandings challenge the prescriptions of reform efforts such as science literacy standards as Project 2061 conceives them. In order to make a case for this claim, I will first consider some ideas from a tradition of philosophy known as *hermeneutics*.

## HERMENEUTICS AND LITERACY

So far, I have generally been discussing philosophy (of science) in terms of the history of Anglo-American thought which basically follows in the traditions of post-positivism and pragmatism. These philosophers commonly concern themselves with questions about rationality, justification, and inference, and *language* has often played a major role in these views in a variety of ways. On the other hand, while also focusing on language, the hermeneutic tradition developed out of a concern for the interpretation of texts, especially biblical texts. Gallagher (1992) notes a related concern for interpretation in the context of education which dates back to the ancient Greeks' learning of poetry. In developing his view of the connection of hemeneutics with education, he draws from the lines of thought developed since the early nineteenth century by, for example, Friedrich Schleiermacher, Wilhelm Dilthey, Paul Ricoeur, Martin Heidegger, Hans-Georg Gadamer, Jürgen Habermas, Jacques Derrida, and Michel Foucault.

Hermeneutics is commonly referred to as *a theory* of interpretation, but the way I am using the term, it refers to views of the limits and boundaries of interpretation which all draw from a larger understanding of interpretation. As views on interpretation, hermeneutics largely concerns the communication of meaning through text, but it has come to involve much more than just written text or speech. "*Language* is a central concern of hermeneutics because of its importance in the process of interpretation" (Gallagher 1992, 5), and, since language involves much more that just textual phenomena, hermeneutical

concerns also include human and social processes commonly associated with the wider context of language and education as well. As Gallagher explains his work:

> One of the aims of this book is to show that a nontextualist, philosophical hermeneutics is possible, precisely by employing the more inclusive model of educational experience in place of the narrow textual paradigm. (Gallagher 1992, 8)

Language is essentially the subject matter of hermeneutics, but language includes more than just reading. "The human being encounters the world and everything in it through language" (Gallagher 1992, 6). Scientific literacy efforts, as should be expected, also emphasize linguistic competencies and communication.

In focusing on understandings which are alleged to be fundamental for scientific literacy, R & A make certain explicit and implicit assumptions about interpretation, meaning, and knowledge. These generally concern the production and transmission of scientific knowledge.

Although R & A admit that within the scientific enterprise scientists often disagree and battle, "scientific inquiry" according to their view ultimately resides in the application of logic, observation, confirmation, and the elimination of bias. They devote little effort to explaining bias, controversy and change in science. As such, their emphasis is on showing how science succeeds and progresses because of the superior methods, and the rational and ethical behavior that

individual scientists employ and in spite of social influences and conflict.

Further, R & A assume that there is a core set of facts and skills required or used by the general scientific community, that this body of knowledge (those aspects most applicable to the general population) can be extracted or abstracted by a select group of professionals, that there is a way to formulate distinct aspects of this knowledge as minimal competencies or standards, and that there is a way or ways to transfer this knowledge to students and subsequently to determine if they have achieved the minimal competencies (outcomes). *Benchmarks for Science Literacy* lists the set of minimum competencies or "thresholds" which are meant to determine whether or not a student has acquired these "objective" understandings of science, that is, whether or not a student is scientifically literate.

In this sense, *literacy* refers to the meanings and understandings of the culture that people *should* share. For scientific literacy, these meanings and understandings that everyone should share reside in ways of thinking, including values, attitudes and skills. As such, scientific literacy shares many of the assumptions of cultural literacy.

Gallagher argues that the cultural literacy movement and the critical thinking movement in education exemplify a *conservative hermeneutic* approach or what I would call a *modern* (as opposed to *postmodern*) approach to interpretation (Gallagher 1992, 213); I wish to add scientific literacy to this category. The explicit attempt to describe rules for rational thinking or universally applicable values

captures the spirit of the conservative approach. "The appeal to rational criteria which transcend any particular situation characterizes the notion of application in both cultural literacy and critical thinking" (Gallagher 1992, 235). Gallagher recommends a "moderate" hermeneutic approach, and I ultimately follow him on this. Since I recognize the need for science educators and students to examine these issues, I set out briefly below the range of positions.

In order to describe the *moderate hermeneutic* approach, it is helpful to consider the extreme views. Conservative hermeneutics entails certain principles of objectivity and reproduction; in contrast *radical* hermeneutics as developed by Derrida and Foucault denies the possibility of objective interpretation or original meaning. Rather than aiming to interpret the text according to the application of certain methods or canons which allow the reader to get at the intended meaning of the author, radical hermeneutics attempts to *deconstruct* the meaning of a text. Instead of searching for an interpretation which accesses the truth found in the text or the original meaning, the point is to play off the text against itself in order to challenge metaphysical notions such as "meaning" (Gallagher 1992, 11). Radical hermeneutics has been understood to lead to extreme forms of relativism since it suggests that any such version of the world is contingent and relative. Gallagher situates *moderate* hermeneutics between the two poles characterized by radical and conservative hermeneutics. Language "keeps us from gaining absolute access to any textual meaning" while at the same time "it enables *some* access to textual meaning" (Gallagher

1992, 9). In other words, the reader's participation with text in the process, that is, the dialogic character of interpretation, implies both subjective and objective sides to interpretation.

> No matter how we read Plato, for example, we never end up with Milton; the text itself constrains our interpretation. Subjective and objective interpretations, rather than being the only two possibilities, are two unattainable extremes of interpretation (Gallagher 1992, 10).

What are the implications of this view for science education?

Gallagher states that "prescriptives have relevance only to particular and local contexts and so must be designed on that level" (Gallagher 1992, x). In other words, *how* a text is interpreted, what it *means*, depends on some cultural practice or language game in which the question arises. For example, it would be futile to formulate rules which allowed for a universal interpretation of the Magna Carta which captures the *meaning* intended by the writers as well as the *meaning* that I get out of reading the text. This would assume that not only does the textual meaning remain constant throughout time, but the meaning is also, if interpreted correctly, the same each time I interpret it. Both of these assumptions are flawed. Linguistic practices, prejudices, traditions, and applications are always practices of localized communities. Gallagher cites Geertz's notion of "local knowledge" in this regard. The point of Geertz's (1983) method is to attempt to recover the reasoning or thinking of individuals within the local contexts and diverse practices so as to try to figure out what "they

think they are up to" (Gallagher 1992, 336). Gallagher puts the problem in terms of education and biases:

> (I)f in the educational context language biases educational experience, and if the language of schooling fluctuates from one school to another, depending on type of school, location, social class of students, and so forth, then biases are always regional or local. Any prescriptive designed to remedy such bias must begin with its local description. In a local hermeneutics the direction of movement is from the particular to the universal. One does not employ a universal prescriptive to determine interpretation in the specific situation. (Gallagher, 1992)

Gallagher describes *Pedagogy of the Oppressed* (Freire 1970) as a local prescriptive approach. The point is to start with the student's own cultural context. Rather than having the "ends" or goals comes first, as with Project 2061 (Ahlgren and Rutherford 1993), the learning is introduced by way of the shared meanings of the *student's* culture. As such, centralized or predetermined truths should not be the basis of educational programs. Rather, teacher and students engage in dialogue concerning the topics or "themes" to be explored, and so students come to analyze *their own* conceptions, misconceptions or interpretations. "*To study is not to consume ideas, but to create and re-create them*" (Freire 1985). As Gallagher notes, "For Freire it is important to take into account the students *in their situation*; the educational program must be planned from the bottom up, rather than from the top down" (Gallagher 1992, 338). Thus, we return to the same questions raised in Chapter One: How do we begin to conceptualize alternatives to the top

down approach to reform? The local and moderate hermeneutic approaches suggest some starting points, but it is perhaps more important for science educators and students to engage in the debates and conversations by examining the range of positions.

*Postmodernism* has become the catchword for opposition to the absolutism and authoritarianism attributed to positivistic, conservative hermeneutic, or *modern* views. A number of recent writers explicitly employ postmodern views of education (Doll 1993, Aronowitz and Giroux 1991), but even among postmodern recommendations, there is confusion as to implications of postmodernist views for education. For example, I have discussed the range of hermeneutical views. Similarly, there is a range of positions with regard to constructivism and cognitive science in science education, and these tensions share several of the concerns surrounding postmodernism.

The territorial lines in science studies are commonly drawn with respect to the commitments to various types of *constructivism*. There are at least two major strains of constructivism which have significantly influenced science studies: *social* and *cognitive*. However, some of the controversies concerning the clash of these views in the context of science education illustrate significant tensions between diverse constructivist positions.

## CONSTRUCTIVISM AND SCIENCE EDUCATION

One of the most pronounced differences in current usages of "constructivism" is the difference between constructivist views which

focus on the cognitive, psychological or individual aspects of knowledge and those which focus on the social aspects. Simply put, *cognitive constructivism* assumes that knowledge is actively built by the individual subject or learner, and *social constructivism* assumes that knowledge is at least in part a result of non-individual or social relations such as communal negotiations or institutional interests. The former is represented by a tradition of constructivism attributed to Piaget, (for example, see von Glasersfeld 1987, 1988, 1992 and Wheatley 1991; also see Matthews 1994 and O'Loughlin 1992), while Sociology of Scientific Knowledge (SSK) has had a great impact on the latter. These diverse fields are brought to heads in dealing with contemporary questions regarding science learning. One source of tension between the these approaches concerns the role of social versus cognitive constructions in learning, especially learning science, and this tension often leads to debate over ontological commitments to mental structures that post-Piagetian structuralist learning theories entail.

Matthews (1992) has criticized the constructivist epistemology of, for example, von Glasersfeld (1987) and Wheatley (1991). Matthews argues that constructivist epistemology is based on an Aristotelian "empiricist, individualistic, reflective or correspondence--'Spectator'--theory of knowledge," and problems with empiricists' assumptions leads constructivists to a relativist epistemology "without abandoning the [Aristotelian-empiricist epistemological] paradigm itself" (Matthews 1992, 188). By "objectivist epistemology," Matthews means one which distinguishes among the real objects of science (raw material and events

of the world), the theoretical structures, the material and events described by the theory (theoretical objects of science), and the experimental procedures of science. The distinction between theory and reality is important to realist arguments since reality must somehow be the foundation for determining the utility or truth of theory.

> Once the distinction is made, and knowledge is recognized as a process of intellectual production working with real objects that have been described, apprehended, or incorporated by a theoretical object, then the interesting epistemological tasks of evaluating different modes of knowledge production--in terms of fecundity, simplicity, utility, truthfulness--can be commenced. Relativism short-circuits all of this. (Matthews 1992, 193)

Matthews is promoting a realism which he claims constructivists deny. Two assumptions he makes are particularly troubling, however: that constructivist epistemology is based on the Aristotelian spectator theory of knowledge, and that constructivism (with the empiricist problems) leads to relativism. The controversies regarding constructivism discussed below suggest that the range of positions regarding constructivism is much broader than Matthews acknowledges. In short, for Matthews (1992) many of the problems with constructivism come from what he takes to be its relativistic tendencies, but it is unclear whether constructivism is as homogeneous as Matthews suspects. Debates among constructivists illustrate some of the diversity in constructivist stances.

The clash between two different self-proclaimed constructivist positions represented by Roth (1993) and Lawson (1993) exemplifies the extreme contrast possible in constructivist positions. While Lawson et al. (1991) claim to provide experimental support for the view the knowledge is socially constructed, Roth (1993) accuses Lawson et al. (1991) of the kind of objectivism and realism that Matthews supports.

> First, Lawson et al. seem to accept an ontology of a real and objective world independent of our human ways to categorize this world....Second, from an epistemological perspective, Lawson et al. seem to assume that our knowledge is a reflection of, or isomorphic to an objective reality. Accordingly, they refer to the 'acquisition of concepts,' the 'precise meanings of concepts,' and the teacher's ability to 'tell' what a concept is (Matthews 1992, 799).

On the other hand, Lawson (1992) describes Roth's view as an extreme constructivism which seems to Lawson to imply a sort of relativism. Lawson goes on to argue for a strong empiricist correspondence view:

> Thus, contrary to Roth's belief that discourse is the most important mechanism for testing knowledge claims, knowledge claims are tested through the deduction of their implied consequences and through a comparison of these consequences with data gathered from experiments conducted in the 'world out there' in as controlled a fashion as possible (Lawson 1993, 806).

This dispute displays the tension between realist and relativist tendencies in constructivist learning theory that presents a particularly difficult problem in the context of science education.

A similar controversy concerns the use of mental structures as in forms of post-Piagetian structuralism. O'Loughlin argues that the

Piagetian form of constructivism "is flawed because of its inability to come to grips with the essential issues of culture, power, and discourse in the classroom" (O'Loughlin 1992, 791). Piaget held that the intellectual processes of children progress through four definite stages of development. Thus, education requires the assessment of the child's intellectual stage in order to determine which experiences are most appropriate and engaging. But, more to the point here, Piaget emphasized that children actively *construct* their concepts, including scientific concepts like space and time, by engaging in the resolution of conflicts (disequilibrium) which arise from experience. It is constructivist in that it requires that the student be the initiator or active builder of concepts. However, Piaget's model is also structuralist in that it "posits evolving logico-mathematical structures in the mind" (O'Loughlin 1992, 793). O'Loughlin maintains that his suggestion is more than simply attaching a cultural dimension or appendage to current Piagetian or cognitive developmental models. "Rather, we need to center our energies on understanding the crucial role of discourse as cultural practice in mediating the relationship between knowledge, power, and the formation of consciousness" (O'Loughlin 1993, 1206). O'Loughlin (1992) distances himself from Piagetian constructivism but embraces a form of social constructivist learning theory. As with social constructivist views, his "sociocultural approach" to science education assumes that learning is contextually situated with a subjective side. Unlike Piagetian structuralism which describes thinking in terms of mental constructions

which are independent of cultural context, the constructivist view proposed by O'Loughlin focuses on this context. He explains the roots of his view which further distance it from Piagetian structuralism:

> Wertsch, drawing on the writings of Soviet theorists--most notably Vygotsky and Bakhtin--argues that the central link between the thinking of the person and the influence of the social, cultural, historical, and institutional setting in which the person lives is the *mediational means* the person uses to engage in the construction of meaning. Although many mediational means are available, Wertsch focuses particularly on the uses of language as a crucial component in the meaning-making process. Drawing particularly on Bakhtin's writing, Wertsch argues that the means that we bring to bear in communicating and interpreting our experiences are necessarily culturally constituted because they are based on language forms that are social in origin. For Wertsch, as for Lave, the person is not seen as a decontextualized individual, contemplating the objective world in isolation and arriving at rational decisions. Instead, reasoning is conceived to be an inherently social and cultural process of meaning making. (O'Loughlin 1992, 811)

While this view of learning has a number of implications for education in general, O'Loughlin here is concerned specifically with its implications for science education. He concludes that

> science teachers, therefore, face the simultaneous challenges of validating their students' personal ways of knowing, introducing them to the powerful speech genres of conventional science, and equipping them with an understanding of the fundamentally socioculturally constituted ways of knowing that underlie science so that the process of doing science is demystified and they do

not feel compelled to defer to the intrinsically authoritative power of the received view (O'Loughlin 1992, 816).

There is a range of constructivist views concerning learning just as there is a range of constructivist views concerning scientific knowledge production. Some constructivist learning theories promote realism while others promote anti-realism. Some adhere to post-Piagetian constructivism, while other represent non-structuralist views. Educators have traditionally focused on Piagetian constructivism while those in science studies have paid more attention to social constructivism. Nevertheless, social constructivist views have been applied to science education (Rosner 1994, Mason and Santi 1994, Tull 1992, Roth 1990, Millar 1989). However, cognitive and social are not mutually exclusive categories of constructivism. It is possible to borrow profitably from both.

## COGNITIVE SCIENCE AND SCIENCE EDUCATION

One of the central aims of cognitive science is to provide naturalized accounts of thinking. This basically means that one does not begin with a commitment to a certain a priori account of knowledge production. Cognitive theorists have attempted a number of approaches to the problems of explaining scientific reasoning given the diverse practices of scientists or humans in general. While some philosophers of science have suggested that scientific reasoning conforms to Bayesian probability theory (see Howson and Urbach 1989), Tversky and Kahneman (1982, 1983) have presented experimental evidence for the claim that

humans do not think in such terms, but, even if this is the case, that does not mean that the way humans think is necessarily unsuited for science. Rather than adhering to principles of pure logic or probability, people may make use of cognitive heuristics like salience, availability, and representativeness. As Solomon explains:

> These heuristics differ from the normative guidelines of logic, probability and confirmation theory which are typically thought of as constitutive of rationality. In fact, the experiments suggest that human reasoning does not even *approximate* such norms of rationality, either in method or results (Solomon 1992, 439).

Solomon argues that biases and heuristics brought about a healthy conflict in plate tectonic theory in geology. The bad news (so to speak) is the fallibility, that is, biases and heuristics may lead to dead ends. The good news is that they may in some cases be valuable to the community as a whole. Says Solomon:

> All I find so far is that in one suggestive case, the revolution in geology, the heuristics brought about division of cognitive labor, and this division of cognitive labor contributed to scientific success. It is likely that heuristics serve us well elsewhere, because they produce distribution of research effort wherever differences in individual experience and prior belief arise, but this remains to be shown by detailed examination of cases (Solomon 1992, 453).

This research suggests that even experts cannot avoid thinking in ways which are underdetermined by "the principles of logical reasoning" and purely empirical considerations, but that that is not necessarily a bad thing.

Barsalou (1989) provides an account from cognitive science which draws from Wittgenstein's (1958) notion of concept. The later Wittgenstein proposed that the way humans use concepts or words is *not* in accordance to rules of correspondence to the world but in accordance with rules of use in a language. Concepts, for example, the concept of *game*, are not definable by necessary and sufficient conditions as traditional philosophical theories of meaning require. There are no traits that all games share, nor any that can identify something as being a game. Rather, games share a "family resemblance." A similar view seems to be emerging in cognitive psychology (Barsalou 1989, 1992). As Barsalou concludes:

> Categories are not represented by invariant concepts. Different individuals do not represent a category in the same way, and a given individual does not represent a category in the same way across contexts. Instead there is tremendous variability in the concepts that represent a category. This variability engenders the consideration of intraconcept similarity, namely, how instances of the same concept are related. Intraconcept similarity depends on (a) whether concepts are constructed by members of the same or different populations, (b) whether concepts are constructed by the same or different individuals, (c) recent experiences with the category, and (d) current context (Barsalou 1989, 114).

While Barsalou is very cautious about drawing early conclusions from cognitive science, and he clearly identifies some of the largest obstacles to category theory, some matters should be considered. First, concepts, even scientific concepts, may be more dynamic or unstable than

traditionally assumed, but, second, this does not mean that they are inaccessible and without similarity.

A good deal of attention in cognitive science has been devoted to explaining and describing how conceptual structures are changed, and R & A do make a slight nod toward conceptual change theories:

> [Effective learning] sometimes requires that people restructure their thinking radically....With experience, [young people] grow in their ability to understand abstract concepts, manipulate symbols, reason logically, and generalize. (R & A, 186).

This view parallels the *structuralist* mentality. On the other hand, *poststructuralism*, like the extreme forms found in the radical hermeneutics of Derrida and Foucault, tends to problematize the ontological commitments of accounts which describe "structures" of thinking. Rather, what structuralism considers underlying causes of behavior are themselves seen as contingent human constructions. In other words, while a structuralist would hold that language deals with the transmission of information between users, a poststructuralist would suggest that it is a much more pragmatic and unstable exchange between its speakers (Jameson 1984). Nevertheless, some recent suggestions for science education from the field of cognitive science have developed out of the structuralist perspective albeit with some postmodern influence.

Kitchener (1992) has suggested an epistemological stage model in which science students make progress through the stages of absolutism, skepticism, relativism, toward the higher stage of probabilistic knowledge. He, like Feyerabend (1975), argues that theoretical

pluralism is the norm in science. In other words, scientists commonly disagree about which theories to support, so students should learn that in the history of science scientists have disagreed and used good scientific reasons to back different (even competing) theories. As such, science students must be made aware of the routine (maybe healthy) conflict in the history of science. Kitchener (1992) also suggests that epistemic norms have "changed over the years," yet he maintains that this change may be a "rational affair," meaning scientists have learned which epistemic norms should be retained and which should be abandoned (136).

Nersessian (1989) has argued that the conceptual changes which take place in science learning processes are fundamentally the same as in scientific knowledge production processes. "Understanding conceptual change as it occurs in science and in learning science will require the development of a common cognitive model of conceptual change" (163). Nersessian (1992) argues that abstraction techniques and mental modelling procedures that were used in the construction of a conceptual structure should be employed by science students in the process of learning the concepts. This is similar to the goal of the 1960s NSF reforms which emphasized the learning of the processes of science by "doing." The differences between Nersessian and the earlier NSF reforms consist mainly in the way the phrase "processes of science" is interpreted. NSF projects generally took this to entail engaging students hands-on with modern idealized versions of scientific methods such as "data gathering" or "hypothesizing." Nersessian's goal is to

attempt to recover the thinking process(es) that *the scientists* actually went through, that is, what *they* were thinking, in order to understand their discoveries, that is, the concepts. The general purpose is, nevertheless, similar with respect to the what classroom science can offer. Both are suggesting ways in which to improve the ability of students to think and act as scientists by encouraging students to take the scientists' perspective. This is also the approach Pitt (1990) proposed but from a more historical perspective.

Nersessian (1994) outlines the research agenda of cognitive history of science, and contrasts it to traditional approaches. The implications she draws for education represent a significant departure from much of the philosophy of science presented in traditional science education, however, the emphasis on cognitive science suggests that this view presents at least some opposition to many claims made in the sociology of science. Nevertheless, because the view attempts to integrate social and cognitive dimensions of knowledge production, Nersessian does not consider this view in contention with descriptions from the sociology of science. Cognitive history, rather, aims to create a synthesis between historical case studies and investigations of human reasoning and representation (cf. Pitt 1990). Such views suggest a more flexible or "historicized" notion of cognition than previous views, such as Lakatos (1978) and Laudan (1977), which presumed that there are universal ahistorical rules of rationality. This resonates with the postmodernists' rejection of grand narratives. However, while "thinking practices" must be contextually situated, they are

nevertheless accessible and important to the study of science. The importance of the history of science to science education for Nersessian lies in its ability to provide "a repository of strategic knowledge of how to go about constructing, changing, and communicating scientific representations" (33) rather than intending simply to provide great stories of surpassing cultural significance. Thus, Nersessian finds instructional value in the history of science for science students. Reeves and Ney offer a similar rationale for the inclusion of constructivist understandings in science teaching practices:

> when students come to understand that science was constructed by people in the first place, for reasons and in specific circumstances, they develop more confidence in their abilities to reconstruct this knowledge for themselves, integrating it with their existing knowledge by questioning, relating, replacing, and speaking (Reeves and Ney 1992, 196).

These views argue that there are instrumental cognitive reasons for students to study the social construction of science. For example, the perspective provided by social constructivism can make learning science less intimidating and easier to assimilate into the student's own understandings.

But the field of cognitive science is diverse. While borrowing from, among other fields, cognitive psychology and constructivism, cognitive science makes a variety of prescriptions for science education. This is in part a reflection of the lack of unifying theories in the field. Piagetian developmentalism as well as social

constructivism have influenced both science education and cognitive science, but there has been little synthesis of the two views. While social constructivist views have focused on the local communicative settings or discursive practices, Piagetian constructivist views have focused on the development of cognitive abilities. The recourse in science education has been to defend one or the other approach against accusations of extreme objectivism or relativism. However, there is room for a moderate stance. The view of scientific concepts or categories as dynamic and unstable mental constructs allows for a social as well a post-Piagetian description of local *and* developmental construction of knowledge. This can avoid many troublesome extremes of relativism and absolutism, as well as provide the basis for a broader notion of what science education can include.

## CONCLUSION

The quest for scientific literacy makes several contentious assumptions. First it assumes that there is a set of objective concepts or interpretations concerning the nature of science which students should come to possess, and that these can be put in the form of statements which define minimal competencies. Second, it assumes that there are scientific ways of thinking and behaving which are describable in terms of "scientific inquiry" and "scientific habits of mind." For R & A, these represent the cognitive dimensions of science which consist of scientific thinking, or the reasoning, computational skills, and rational processes used by individual scientists, as well as the

scientific attitudes and values which act as norms of the scientific community.

However, a number of debates suggest that scientific inquiry, or human thinking in general, is not so easily described. More to the point, current understandings of science and learning suggest that there are no "standard" ways of knowing or doing science. In other words, these contemporary debates suggest that we should be very wary of texts which purport to contain the one set of universal knowledge claims, values, and attitudes which everyone should have. These debates include a number of disputes associated with postmodernism including those involving hermeneutics, constructivism, and relativism. In general, however, there is movement toward viewing many of the questions about the nature of science and scientific inquiry as *empirical* questions. Moreover, some "moderate" approaches are beginning to emerge which attempt to account for both social and cognitive explanations of science in naturalized manners or in response to postmodern critiques. I suggest that such controversies themselves can be instructive to students and teachers. Scientific literacy standards suggest the opposite.

In order to define scientific literacy standards, R & A rely on a conservative hermeneutic or modern vision of science education in which the objective knowledge produced by science is stated in text or standards and transmitted to the student untransformed. While postmodernists sometimes go to the other extreme in denying the possibility of any such knowledge or transmission thereof, clearly one

of the main emphases in science studies is on the ramifications of local *differences* in linguistic communities.

Thus, the conclusion to which a moderate approach with respect to these postmodern concerns leads is that any attempt to spell out in impartial language *the* nature of science is immediately suspect and must be understood as a partial narrative. In this regard, the opposing viewpoint is instructive. Postmodernism invokes a spirit of skepticism concerning resolutions of matters such as those suggested by literacy standards, but this is also coupled with a rejection of an authoritarianism especially with regard to the public's understanding of science or scientific literacy. Thus, the range of philosophical positions that oppose the view given by scientific literacy can increase the public's awareness of contemporary questions regarding the production and dissemination of scientific and school knowledge.

# Conclusion

I began this study by showing how Project 2061 continues in the top-down tradition of curriculum reform. In general, top-down approaches to science education reform have had little coherent impact, and the view of the nature of science presented in R & A is very controversial given contemporary research in science studies. The gulf between science education and science studies parallels a number of other long standing controversies over how best to explain science. Thus, the concern for getting "the nature of science" straight in school science is not a new concern, and it is clearly not a simple one to address.

If the goal is to teach the nature of science in terms of scientific inquiry or scientific thinking, then, as I have suggested, the range of positions that dot the contemporary landscape can be helpful. In the spirit of Socrates, moderation between the extremes may be what is called for. Moderate approaches can be found in a number of contemporary views, and I have only suggested a few possible sources. However, the extreme positions might better indicate the major issues at stake in science studies. These controversies are as healthy to science education as scientific controversies are to science. Moreover, these understandings in science studies force the educator to reflect on her own epistemological commitments and their place among the wider discourse and classroom phenomena. Thus, science studies should play a

role not only in reconceptualizing the content of science education but also in developing better science education policy.

However, science studies should not be mistaken for *the* panacea for public science education. Rather, in the context of science education, it is best seen as suggesting ways to learn from controversies concerning the nature of science; ways to reconceptualize scientific knowledge and science education; ways to interest and motivate a diversity of students; ways to encourage critical and empirical practices; and ways to reflect on and reconceptualize the public's interest in science.

Moreover, contemporary views of science and knowledge also provide a basis for reconceptualizing educational research. Science, for Dewey, had great potential to contribute to education not only as subject matter but also as a tool for educators. He saw education and science so intertwined because he saw learning and knowledge equally intertwined. Education should *use* the tools of science as much as *teach* those tools, but learning how to use tools comes from using them. Learning to think critically comes from thinking critically even with respect to the nature of scientific thinking. This means critically examining research and controversy devoted to the topic. But there is no answer waiting to be discovered. Rather, there are incomplete and problematic answers which can be defended and rejected on grounds which themselves can be defended and rejected. Similarly, there are no universal goals of education waiting to be attended to. Rather, there are numerous and conflicting individual and public goals of education,

and epistemological and philosophical presuppositions are implicated in the controversies concerning these goals. Project 2061 represents one significant contemporary view of *the needs* of science education, but it is not unchallenged.

There are a number of fundamental problems with scientific literacy standards that need further development than can be given here. First, there are major philosophical and practical problems with identifying a common core of scientific knowledge that represents what is most important or applicable to the lives of every American. There is no single "nature of science," and there is no single "reason for every American to study science." Second, there are similar challenges to the identification of a common set of problems in education. As Dewey states,

> because it is the individual that knows his own troubles, even if he is not literate or sophisticated in other respects, the idea of democracy as opposed to any conception of aristocracy is that every individual must be consulted in such a way, actively not passively, that he himself becomes a part of the process of authority, of the process of social control; that his needs and wants have a chance to be registered in a way where they count in determining social policy. (Dewey 1938c, 295)

Not only do classrooms and schools exhibit an extreme variety of environments, but individuals and communities differ significantly over the values and goals, and therefore the measures of success and failure, of education. Third, there are problems with implementing common standards. Even Tyler said of his questions about curricular goals,

methods, and content that "the answers will vary to some extent" across level and school (Tyler 1949, 1-2), and Project 2061 is explicitly *not* directed at producing uniform curriculum (R & A, xii, AAAS 1993, xii). However, R & A fail to recognize the extent to which factors in the particular situations influence individuals, *their* goals, and *their* interpretations.

Science literacy standards attempt to answer a set questions that have been a growing concern to contemporary communities; mainly, what should everyone know about science? However, in doing so, they raise larger questions about the nature of science and the production and diffusion of scientific knowledge and knowledge in general. In this regard, science studies has much to offer those interested in science education reform, but there is no clear consensus concerning these matters. In general, there is a greater concern for giving a voice to those who traditionally have been voiceless. In terms of science literacy, this suggests that the students and communities that are served by the schools should be empowered to engage in decisions about science and science education that affect their own lives. But with choice comes a responsibility to first understand the issues and questions. To this end, I have attempted to spell out a number of questions associated with general science education reform. If and when faced with science literacy standards, communities, schools, teachers, and students should be able to deal in an informed fashion with questions about the content and measures of science literacy, and particularly, about whose voices are heard in these matters.

NOTES

[1] Fensham's (1992) cite reads as follows: AAAS 1989. *Science for All Americans*. A summary report of Phase I of Project 2061. Washington, DC: American Association for the Advancement of Science [page 162]. This is an earlier version of Rutherford and Ahlgren (R & A) 1990. In R & A the passage Fensham cites is found on page 206.

[2] Darling-Hammond and Snyder cite the studies of Gallagher (1967) for the first claim quoted, Rothman, Welch, and Walberg (1969) and Walberg and Rothman (1969) for the second, and Carlson (1965) for the third.

[3] Interest theory is a product of Marxist theory in general; it has been applied to science studies mostly by way of the sociology of scientific knowledge to be discussed in Chapter Two below.

[4] Hempel (1958) provides a detailed discussion of Skinner's argument that theoretical terms should be discarded in favor of direct causal links between observables. Hempel shows how Carnap's logic can be used to reduce theoretical statements or entities to observation sentences or observables. However, Hempel ultimately sides against Skinner because of pragmatic (as opposed to purely logical) functions of theory. Similarly, with respect to education, Skinner (1968) recommended that instruction be divided into many intermediate observable steps with positive reinforcement contingent on the completion of each step or observable competency.

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**VITA**

**Daniel R. Dunlap**

1409 Karr Lane
Blacksburg, VA 24060-2670
Home: (703) 552-7415
Office: (703) 231-6630
E-Mail: DUNLAP@VTVM1.CC.VT.EDU

**EDUCATION:** **Virginia Polytechnic Institute and State University** (VPI&SU)

Ph.D. candidate (current) Science and Technology Studies
M.S. Science and Technology Studies, 1995
B.A. Philosophy, 1987

**EXPERIENCE:**

Instructor, Montgomery County Public Schools, VA
Physics, Earth Science, Life Science, and Mathematics
January 1988 - June 1991

Instructor, Upward Bound, VPI&SU
July 1990 - June 1991

**AWARDS:**

Graduate Assistantship, Science and Technology Studies/Liberal Arts and Science, Academic Advising
January 1994 -

**PUBLICATIONS:**

Contributing author:

LaPorte, J.E., and Sanders, M.E. (1995 in press). *Technology, Science, Mathematics Connection Activities.* Lake Forest, Ill: Glenco.

**SERVICE:**

Graduate Student Representative, Curriculum Transition Committee
Center for Interdisciplinary Studies
November 1994 - May 1995

Daniel R Dunlap