Research Monograph No. 12

Current Conceptions of Science Achievement in Major Reform Documents and Implications for Equity and Assessment

Okhee Lee
National Institute for Science Education (NISE) Publications

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Abstract

The construct of science achievement—what K-12 students should know and be able to do in science—is central to science education reform. This paper presents current conceptions of science achievement in major reform documents and considers implications for assessment and equity in the context of standards-based and systemic reform. The paper reviews documents on science content standards (NSES and Project 2061), performance standards (New Standards), and large-scale assessment frameworks (1996 NAEP and TIMSS). The results indicate that there is an overall agreement on the conceptions of science achievement. Although equity is emphasized as the key principle, the aggregated view of science achievement in these documents is largely defined in the tradition of Western science. Alternative perspectives from multiculturalism, feminism, critical theory, and postmodernism are considered to develop a more inclusive and broader conception of science achievement for students from diverse backgrounds.
Introduction

Standards-based and systemic reform has an overarching goal: high academic standards for all students (McLaughlin, Shepard, & O’Day, 1995; Smith & O’Day, 1991). In science education, the goal of “science for all” is emphasized in defining and specifying science content standards by professional science education organizations in international and national contexts. The recent developments in science content standards are reflected in large-scale assessment efforts to align assessment with the new content standards.

The construct of science achievement—what K-12 students should know and be able to do in science—is central to science education reform. Major reform documents in science content standards and assessment present varying degrees of commonalities and differences in their views of science achievement for all students. Considering these variations, there is a need to develop an aggregated view of science achievement based on a synthesis of these reform documents. There is also a need to consider the implications for equity and assessment in terms of what these documents promise and what they actually provide.

Current conceptions of science achievement in major reform documents are examined for three main purposes: (a) to review and analyze conceptions of science achievement in reform documents and to present an aggregated view of science achievement; (b) to consider the implications of this view of science achievement for equity; and (c) to consider the implications for large-scale assessments. These issues are addressed in the context of standards-based and systemic reform in large education systems, including state and district levels.

Major reform documents are cornerstones for current efforts for standards-based and systemic reform (Collins, 1998; Porter, Smithson, & Osthoff, 1994; Smith & O’Day, 1991). Because of their importance, these documents impact policy decisions for curriculum, instruction, and assessment at state and district levels. Policy guidelines, in turn, impact classroom practices through multiple venues (Knapp, 1997). In addition to their influences on policies and practices, major reform documents are also topics of scholarship for theoretical (Eisenhart, Finkel, & Marion, 1996; Rodriguez, 1997) and policy debate (Cohen, 1995; Donmoyer, 1995; Elmore, 1995; Kirst & Bird, 1997; Smith & O’Day, 1991). A comprehensive review and a critical analysis of major reform documents can benefit a variety of educators, including policymakers, subject matter specialists, assessment experts, and evaluators of standards-based and systemic reform in general, as well as scholars and practitioners involved in science education.

The major reform documents examined include (a) two sets of documents on science content standards, the National Science Education Standards [NSES] (National Research Council [NRC], 1996) and Project 2061 (American Association for the Advancement of Science [AAAS], 1989, 1993); (b) a set of documents on performance standards in the New Standards Project (National Center on Education and the Economy [NCEE], 1997a, 1997b, 1997c; 1998); and (c) two sets of documents on assessment frameworks, the 1996 National Assessment of Educational Progress [NAEP] (National Assessment Governing Board [NAGB], 1994, 1996) and the Third International Mathematics and Science Study [TIMSS] (Martin & Kelly, 1996; McKnight, Schmidt, & Raizen, 1993; Robitallie, McKnight, Schmidt, Britton, Raizen, & Nicol, 1993). Related documents and publications by these reform projects are also considered.
The reform documents are selected based on the following criteria. First, they provide guidelines for standards-based and systemic reform in large education systems, including state and district levels. Second, they present comprehensive views of science and science education. Third, they cover science content for K-12 grade levels. Finally, they are key documents that are representative of content standards, performance standards, and assessment frameworks in science education. Based on these criteria, the paper does not include some noteworthy efforts. For example, National Science Teachers Association documents (1992, 1995, 1996) are limited to the four science disciplines (biology, chemistry, earth and space science, and physics) traditionally studied in secondary school, grades 6-12. The Advanced Placement tests are administered to a small population of advanced high school students. The National Educational Longitudinal Study (NELS) focused only on eighth-grade students before the current reform had been implemented.

After reviewing the conceptions of science achievement in the reform documents, implications of these conceptions for equity are considered. For this analysis, the literature from multiculturalism, critical theory, feminism, and postmodernism is reviewed. In considering the implications for assessment, the literature concerning content standards and equity in large-scale assessment is reviewed. In addition, the literature on standards-based and systemic reform as it relates to science standards and equity is also reviewed.

The paper reviews a range of perspectives with regard to science achievement, equity, and assessment. The paper describes the perspective on science and science achievement based on the tradition of Western science in major reform documents, as opposed to alternative perspectives from multiculturalism, critical theory, feminism, and postmodernism. Based on this review, the paper seeks to offer a balanced perspective that integrates different, sometimes conflicting or opposing, perspectives in promoting science achievement for all students in standards-based and systemic reform.

Conceptions of Science Achievement in Major Reform Documents

Three issues are addressed in this section. First, conceptions of science achievement in each set of reform documents are described. Then, commonalities and differences in the views of science achievement among these documents are examined. Finally, an aggregated view of science achievement is presented. The review of these documents provides the framework for considering the implications of this view of science achievement for equity and assessment in subsequent sections of this paper.

Review of Major Reform Documents

For each set of documents, brief descriptions about its background, purposes, and the conception of science achievement are presented. These descriptions are based on the documents without commentary or interpretation. The descriptions do not reflect political or historical contexts in which the documents were developed or implemented (for political contexts, see Collins, 1998, and Kirst & Bird, 1997; for historical contexts, see Hurd, 1993, 1994). The summary of the conceptions of science achievement in these documents is shown in Table 1. This table is organized using the categories of standards in NSES because this document represents an effort to establish a general agreement of the science and science education communities of over 150
associations in the nation (Collins, 1998). The table provides an overview of commonalities and differences among the five sets of documents at the categorical or topical level (see Raizen, 1997, for general descriptions about these documents).

Several points need to be made about Table 1 and the discussion that follows. First, the sequence of the eight categories of NSES standards is slightly changed to fit with the other four sets of documents. Second, in addition to the categories of “content standards” stated in NSES, the table includes “process standards.” The distinction between “content” and “process” standards is based on mathematics standards, even though the authors did not state this distinction (National Council of Teachers of Mathematics, 1989; also see AAAS, 1993, p. 209; Romberg, 1997). Content standards generally indicate what students should know (i.e., knowledge and understanding), and process standards indicate what students should be able to do (i.e., abilities and skills). Science process is not independent of science content; instead, process standards cut across content standards. New Standards, NAEP, and TIMSS identify science process standards. Although NSES and Project 2061 do not identify them as such, the documents emphasize process standards throughout the texts. Finally, the categories and terms in Table 1 are actual descriptors and expressions used in these documents. The documents sometimes use the same terms with different meanings and different terms with similar meanings.

National Science Education Standards (NSES). NSES (NRC, 1996) claims to present “a vision of science education that will make scientific literacy for all a reality” (p. ix) and to provide a roadmap for how to achieve the goal. The development of NSES was guided by the following principles: (a) science is for all students; (b) learning science is an active process; (c) school science reflects the intellectual and cultural traditions that characterize the practice of contemporary science; and (d) improving science education is part of systemic education reform (pp. 19-21). The core of NSES involves science content standards, while “the separate standards for assessment, teaching, program, and system describe the conditions necessary to achieve the goal of scientific literacy for all students described in the content standards” (p. 13).

The content standards define “what students should know, understand, and be able to do in natural science” over the course of K-12 science education (p. 103). NSES presents a total of 77 sections representing separate learning goals. While emphasizing that “scientific inquiry is at the heart of science and science learning” (p. 15), the document presents eight categories of science content standards for grade ranges K-4, 5-8, and 9-12:

- Unifying concepts and processes
- Science as inquiry
- Physical science
- Life science
- Earth and space science
- Science and technology
- Science in personal and social perspectives
- History and nature of science

Project 2061. The Science for All Americans (AAAS, 1989) document is a major milestone in shaping the discourse of science education reform since late 1980s. It provides a definition of twelfth-grade scientific literacy that enables all students to become educated citizens in society.
Table 1
Conceptions of science achievement: Categories of content and process standards from major reform documents

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<td>The human organism</td>
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<td>Science as inquiry</td>
<td>The nature of science</td>
<td>Scientific investigation</td>
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<td>Using tools, routine procedures, and science processes</td>
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<td>Scientific thinking</td>
<td>Practical reasoning</td>
<td>Theorizing, analyzing, and solving problems</td>
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*Although the NSES and Project 2061 documents do not identify process standards, these standards are emphasized throughout the texts.*
Subsequently, *Benchmarks for Science Literacy* (AAAS, 1993) specifies the components of science content in greater detail, including 855 benchmarks at grade ranges K-2,3-5, 6-8, and 9-12. Because of its specificity of learning outcomes, the *Benchmarks* document has often been used as a guideline for K-12 science curriculum.

Project 2061 defines science broadly to include natural science, mathematics, technology, and social science. The science content is organized thematically under four major dimensions (see the list below; AAAS, 1989, p. ix). Then, the categories of the science content are outlined in terms of what students should know and be able to do as members of a scientifically literate society. Project 2061 highlights “both scientific knowledge of the world and scientific habits of mind” as fundamental in science and science learning (1989, p. 190). The four major domains and specific categories include:

**The nature of science, mathematics, and technology**
- The nature of science
- The nature of mathematics
- The nature of technology

**Knowledge and skills in science**
- The physical setting (physical and earth science)
- The living environment (life science)
- The human organism (life science)

**Knowledge and skills in related disciplines**
- Human society
- The designed world
- The mathematical world

**Perspectives on science**
- Historical perspectives
- Common themes
- Habits of mind

**New Standards.** The New Standards Project is designed to build an assessment system for school districts and states “to measure students’ progress toward meeting national standards at levels that are internationally benchmarked” (NCEE, 1997a, 1997b, 1997c, p. 2). New Standards focuses on specifying performance standards and developing performance measures that teachers can use in English language arts, mathematics, science, and applied learning.

While content standards specify “what students should know and be able to do,” performance standards go to the next level by specifying “how good is good enough” in attaining the content standards (p. 3). Performance standards translate content standards in a form so that assessment activities can be prepared. The New Standards assessment system has three interrelated components: performance standards, on-demand examinations, and procedures for portfolio assessment. By summer 1998, New Standards had developed performance standards at the elementary, middle, and high school levels (NCEE, 1997a, 1997b, 1997c) and an on-demand examination (called reference examination) at the elementary school level (NCEE, 1998).
The performance standards are derived directly from the science standards in NSES and Project 2061 and, to some extent, international documents including TIMSS. The eight categories of performance standards in science are in two dimensions: (a) conceptual understanding that reflects the content standards in NSES and Project 2061 and (b) “areas that need particular attention and a new or renewed emphasis” (1997a, p. 130), which represent important aspects of scientific inquiry as defined in NSES and Project 2061. New Standards includes eight categories of performance standards in these two dimensions at the levels of elementary school (by the end of fourth grade), middle school (by the end of eighth grade), and high school (by the end of tenth grade):

**Conceptual understanding**
- Physical sciences concepts
- Life sciences concepts
- Earth and space sciences concepts
- Scientific connections and applications
  - Big ideas and unifying concepts
  - The designed world
  - Health, environment, safety, resources
  - Science as a human endeavor
  - Historical and contemporary impact of science

**Areas for particular attention**
- Scientific thinking
- Scientific tools and technologies
- Scientific communication
- Scientific investigation

**National Assessment of Educational Progress (NAEP).** NAEP has been the only national-level assessment in various subject areas since its inception in 1969. The NAEP reports provide descriptive information about student achievement in subject areas, including science, for a national sample at grades 4, 8, and 12. They also provide group comparisons in terms of ethnicity, gender, and other demographic variables. The reports describe the relationships between achievement and certain background variables, such as time spent on homework and parents’ educational levels. In addition to the national sample data, NAEP reports have provided state-by-state results on a voluntary basis since 1990.

Because of its prominence in assessment at the national and state levels, NAEP has tried to reflect changes in curriculum and emerging notions of teaching and learning, while maintaining the continuity of information that has been gathered in a long-term trend design (Glaser & Linn, 1997). The conflicts in maintaining the balance between change and continuity over the years present complicated questions (Jones, 1996). Along with the recent development of content standards, “the 1996 NAEP Science Achievement attempts to reflect a comprehensive, contemporary view of science so that those affected by the National Assessment are satisfied that it addresses the complex issues in science education without oversimplification” (NAGB, 1996, pp. 2-3). The 1996 NAEP science assessment is regarded as the best available means for determining the extent to which students across the nation and in each state achieved science
content standards (Glaser & Linn, 1997; O’Sullivan, Reese, & Mazzeo, 1997). In developing the assessment framework, 1996 NAEP considered Project 2061, NSTA, and TIMSS among its major sources. The framework has four main dimensions, and three of them have specific categories:

**Fields of Science**
- Earth science
- Physical science
- Life science

**Knowing and Doing**
- Conceptual understanding
- Scientific investigation
- Practical reasoning

**The Nature of Science**
- The historical development of science and technology
- The habits of mind that characterize science and technology
- The methods of inquiry and problem solving

**Themes**

*Third International Mathematics and Science Study (TIMSS).* This study is the largest ever undertaken of mathematics and science performance, involving half a million students from 41 countries. The study provides information about student performance in mathematics and science for each country, as well as comparisons of performance among the countries. The study also provides information about contextual variables associated with student performance. These variables include curriculum analyses based on national or regional curriculum guidelines and commonly used textbooks, instructional practices, perceptions of teachers and principals, and instructional environments.

TIMSS developed curriculum frameworks in mathematics and science, which were used for developing achievement tests for ages 9, 13, and the final year of secondary education (Martin & Kelly, 1996; Robitallie et al., 1993). Because TIMSS is an international study, the frameworks were designed to reflect the curricula of the participating countries. The frameworks have three main aspects: (a) subject matter content; (b) performance expectations (i.e., the kinds of performances that students are expected to demonstrate while engaged with the content); and (c) perspectives (i.e., attitudinal and motivational factors). The components of the content and the performance expectations aspects in science achievement tests include the following:

**Content aspect**
- Earth sciences
- Life sciences
- Physical sciences
- Science, technology, and mathematics
- History of science and technology
- Environmental issues
Nature of science
Science and other disciplines

Performance expectations aspect
- Understanding
- Theorizing, analyzing, and solving problems
- Using tools, routine procedures, and science processes
- Investigating the natural world
- Communicating

Commonalities and Differences Among Reform Documents

There is general agreement on major categories of science standards among the five sets of documents, as summarized in Table 1. Differences can also be found in some of the categories. Beyond this categorical analysis, there are both commonalities and differences in underlying views of science achievement among these documents.

Commonalities. According to the analysis conducted by Project 2061, there is about 90% agreement in content standards between NSES and Project 2061 (AAAS, 1996, 1997). NSES also states that “use of Benchmarks . . . complies fully with the spirit of the content standards [in NSES]” (NRC, 1996, p. 15). The performance standards in New Standards are “built directly upon the consensus content standards,” (NCEE, 1997a, p. 3), particularly NSES and Benchmarks for Science Literacy (p. 130). The assessment frameworks by 1996 NAEP and TIMSS also reflect the recent developments of science content standards. Based on this overall agreement, the reform documents reinforce common views of science achievement and form a strong alliance.

Together, these documents define science achievement in a comprehensive manner. Science achievement, i.e., what K-12 students should know and be able to do, includes concepts and theories in physical, life, and earth and space sciences; scientific inquiry or investigation; science with mathematics and technology; science in personal and social perspectives; the nature and history of science; unifying concepts or common themes; and scientific habits of mind. The documents define science achievement at certain depths of knowledge and abilities for all students and at different developmental levels (i.e., generally at elementary, middle, and high school years).

Differences. The documents present noticeable differences in conceptions of science achievement. Main differences are described in three ways: (a) differences between the two sets of content standards; (b) differences among the three assessment frameworks; and (c) differences between the two sets of content standards and the three assessment frameworks.

Despite the overall agreement, important differences reside in the fundamental views of science and science achievement between NSES and Project 2061 (for more detailed discussion, see AAAS, 1996, 1997; Raizen, 1997). First, Project 2061 defines science broadly to include natural science, mathematics, technology, and social sciences, whereas NSES focuses on natural science. The omission of mathematics in NSES has been criticized, especially considering that NSES emphasizes scientific inquiry and that mathematics is integral to scientific inquiry. Second, NSES views scientific inquiry as central in science and science learning, whereas Project 2061
emphasizes scientific knowledge and habits of mind. NSES structures the entire science education system to promote scientific inquiry, and Project 2061 emphasizes conceptual understanding as evidenced by its extensive review of conceptual change research on a wide range of science topics (AAAS, 1993).

Differences among the three assessment frameworks reside partially in the purposes and contexts of the documents. The four categories of science process in New Standards correspond to NSES emphasis on scientific inquiry, and New Standards specifies performance measures for scientific inquiry (NCEE, 1997a, p. 130). Because NAEP tracks the progress in science achievement of U.S. students, it has to maintain the continuity of the assessment framework over the years, while representing the changes at certain times. Because 1996 science assessment is substantially different from the previous assessments, it presents a challenge for a long-term trend analysis (Jones, 1996). TIMSS occurred in an international context and had to consider the curricula of all participating countries.

Several main differences are noted between the two sets of content standards and the three assessment frameworks. First, NSES and Project 2061 include science content primarily, although NSES stresses scientific inquiry and Project 2061 stresses scientific habits of mind as science process. In contrast, the three assessment frameworks emphasize science content and process as equally important. New Standards adds four categories of process standards to complement the content standards of NSES and Project 2061. The 1996 NAEP framework identifies three elements of “knowing and doing science” (conceptual understanding, scientific investigation, and practical reasoning) that cut across three “fields of science” (earth, physical, and life science). TIMSS includes the performance expectations aspect, in addition to the content aspect. Further, the 1996 NAEP and TIMSS assessment frameworks use the matrix of content-process intersections.

Second, there is a difference in the balance of representations or emphases among the standards. NSES and Project 2061 give equal importance to all categories of the standards and do not differentiate the priority of one standard over another (Webb, 1997, pp. 20-21). In contrast, the three assessment frameworks distinguish the importance by assigning differential weights. For example, in terms of the number of assessment items, assessment time, and maximum score points, both 1996 NAEP (NAGB, 1994, 1996; O’Sullivan, Reese, & Mazzeo, 1997) and TIMSS (Martin & Kelly, 1996; McKnight, Schmidt, & Raizen, 1993) emphasize conceptual understanding more than the other process standards across grade levels. New Standards gives special attention to process standards generally to be consistent with its focus on performance assessment.

An Aggregated View of Science Achievement

Based on the analysis of the five sets of documents, an aggregated view of science achievement is presented (see Table 2). Five components of science content and four components of science process emerged in the documents. For each component, key indicators are identified, rendering the component more specific and concrete. These indicators serve as the operational definition of each component.
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Science content. The five components of science content are generally consistent with NSES standards. All of the documents identify three fields or disciplines of science, including physical, life, and earth and space sciences. NSES (NRC, 1996) defines this category of standards as follows: “Science subject matter focuses on the science facts, concepts, principles, theories, and models that are important for all students to know, understand, and use” (p. 106).

The integration of science, mathematics, and technology has been a common expectation in current science education reform, particularly in Project 2061. The five sets of documents identify the role of mathematics in science learning in different ways (see Table 1). Project 2061 emphasizes mathematics as integral to science, whereas NSES does not include mathematics as a key component of science. The three assessment frameworks emphasize mathematics to varying degrees. Because mathematics is involved in all aspects of science learning, it is difficult to specify its role in science learning. In the framework presented here, two aspects of mathematics related to science are highlighted: (a) measurement and (b) statistics and probability.

All of the documents stress technology in science learning. Among many definitions of technology (Raizen, Sellwood, Todd, & Vickers, 1995; see Roth, 1998), these documents consistently use technology to refer to engineering, design, or engineering and design interchangeably. NSES states, “The central distinguishing characteristic between science and technology is a difference in goal: The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs” (p. 24).

The component of science in personal and social perspectives is included in all the documents, except for NAEP. NSES and Project 2061 include a broad range of personal and social issues, whereas TIMSS and New Standards have a limited focus on a narrow range of specific issues. Main topics include health, population growth, natural resources, environmental issues, safety, and natural and human-induced hazards. The current emphasis on science in personal and social perspectives is consistent with the vision of scientific literacy for all students to become educated citizens, rather than for a select few to become scientists. NSES states, “An important purpose of science education is to give students a means to understand and act on personal and social issues” (p. 107). The goal is to help students learn to make informed decisions about personal and social matters based on sound knowledge of science.

All of the documents emphasize the history and nature of science. With regard to the history of science, major discoveries in modern science are emphasized. This historical development is defined in terms of the tradition of Western science since the Copernican revolution. Project 2061 states, “The sciences accounted for in this book are largely part of a tradition of thought that happened to develop in Europe during the last 500 years” (AAAS, 1989, p. 136). The contributions of non-Western cultures to science and technology are only briefly mentioned in NSES and Project 2061.

The nature of science includes the nature of scientific knowledge, the nature of scientific inquiry, and the scientific world view. The nature of scientific knowledge and inquiry is emphasized in all of the documents to varying degrees. NSES focuses more on inquiry; Project 2061 focuses more on scientific knowledge; and the three assessment frameworks include both. The scientific world view is stressed only in Project 2061. The nature of science involves a rigorous process of observation, experimentation, and validation and generates explanations based on evidence,
reasoning, and logic. Based largely on empiricism, objectivism, and positivism, the scientific world view excludes other ways of knowing and other bodies of knowledge, such as spiritual and supernatural accounts of natural phenomena.

**Unifying themes** are emphasized in all the documents, except for TIMSS. Unifying themes indicate “big ideas” or powerful ways of understanding that transcend a range of basic concepts and processes in science and technology (NSE) or in science, mathematics, and technology (Project 2061). Project 2061 states, “Some important themes pervade science, mathematics, and technology. . . . They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design” (AAAS, 1989, p. 155). Based on NSES and Project 2061, the framework here identifies five unifying themes, including systems, models, constancy and change, evolution and equilibrium, and form and function.

**Science process.** Science process indicates what students should be able to do with the components of science content. **Scientific understanding** refers to the knowledge and understanding of key concepts and theories and their applications to explain natural phenomena. This is consistent with “conceptual understanding” in New Standards and NAEP and “understanding” in TIMSS (see Table 1). Based on the definition in NSES (NRC, 1996, p. 23) and science education research (e.g., Kennedy, 1998; Secada, 1997), scientific understanding includes several distinct abilities: (a) acquisition of key concepts and theories in science disciplines; (b) construction of relationships between and among concepts and theories within a science discipline; (c) construction of relationships among concepts and theories across science disciplines; (d) use of concepts and theories to explain and predict natural phenomena; and (e) applications of concepts and theories to new real-world situations.

The five sets of documents use two related terms, “scientific inquiry” and “scientific investigation” (see Table 1). NSES and Project 2061 use inquiry, whereas New Standards, 1996 NAEP, and TIMSS use investigation. Both NSES and Project 2061 use scientific inquiry in a broad sense—“the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (NRC, 1996, p. 23). In contrast, New Standards, 1996 NAEP, and TIMSS use scientific investigation in a more limited and specific way—a systemic observation, a “fair” test (“a test in which only one variable at a time is changed” in NRC, 1996, p. 122), or a controlled experiment. The framework proposed here uses **scientific investigation** as it is used in New Standards, 1996 NAEP, and TIMSS. During scientific investigation, students formulate questions, devise plans to explore the questions, make and revise hypotheses, collect and analyze data, interpret data, generate explanations, and draw conclusions. Students also use appropriate tools and equipment for conducting the investigation.

**Scientific communication** is emphasized in New Standards and TIMSS. Although NSES and Project 2061 do not identify process standards, including scientific communication, the importance of scientific communication is stressed in the text of the documents. NSES emphasizes, “[Teachers] structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse. A fundamental aspect of a community of learners is communication” (p. 50). In the framework presented here, two aspects of scientific communication are highlighted: multiple representations and rules of scientific discourse. In the process of knowing and doing science, students demonstrate their knowledge and understanding
using multiple representational formats, including oral communication, writing, drawings, charts, diagrams, tables, graphs, figures, concept maps, mathematical symbols and models, and computer graphics and simulations (Roth & McGinn, 1998). As students engage in formal and informal discussion of science, they develop an understanding of the rules of scientific discourse.

The component of scientific habits of mind is emphasized in recent reform, especially Project 2061. Project 2061 defines scientific habits of mind in terms of certain values, attitudes, and skills associated with science, mathematics, and technology (AAAS, 1989, chapter 12 and pp. 189-193). Although NSES uses the term “habits of mind” only once (p. 170) throughout its 100 pages on content standards, the document emphasizes scientific values, attitudes, and skills throughout the text (see pp. 50-51). Based on Project 2061 and NSES, scientific habits of mind in the framework here include (a) scientific values and attitudes and (b) thinking skills.

Some of the scientific values and attitudes are generally shared in society and highly regarded as basic human qualities, including curiosity, interest, insight, energy, diligence, persistence, intellectual honesty, and creativity. Others are central to science, including critical and independent thinking, tolerance of ambiguity or uncertainty, openness to new ideas, skepticism, empirical verification, arguments based on logic and evidence, and questioning rather than deferring to authority. In addition to scientific values and attitudes, scientific habits of mind also include thinking skills, such as heuristics of number sense and quantitative reasoning, logical skills, and metacognition in reflecting and self-assessing one’s own learning process and performance.

In summary, several conclusions can be drawn about the aggregated view of science achievement in major reform documents. First, science achievement is conceived in terms of science content and science process, and the components of science process cut across the components of science content. Second, the components of science achievement overlap and relate to one another. Despite such an overlap, understanding the role that each component plays provides insight into its unique contributions as well as its interactions with other components. Third, the view of science and science achievement based largely on the Western science in these reform documents has major implications for equity with students from diverse backgrounds. Finally, an aggregated view of science achievement and identification of its components provide a guideline for assessment. The last two issues will be discussed in the subsequent sections.

**Equity in Science and Science Achievement**

Concern with equity begins with achievement results among diverse groups of students. In the U.S., there are achievement gaps among ethnic, socioeconomic, and gender groups (e.g., National Center for Education Statistics, 1992; National Science Foundation, 1994; O’Sullivan, Reese, & Mazzeo, 1997). In his analysis of trends in science achievement in large-scale databases, including the National Assessment of Educational Progress (NAEP), National Education Longitudinal Study (NELS), American College Testing (ACT), Scholastic Aptitude Test (SAT), and Advanced Placement Exams (AP), Rodriguez (in press) concludes that patterns of achievement gaps are “alarmingly congruent over time and across studies regardless of ethnicity, gender, and grade level.”
Standards-based and systemic reform emphasizes educational equity, along with high academic standards. The focus on equity attempts to address significant achievement gaps among diverse student groups in terms of ethnicity, language, gender, disabilities, and socioeconomic levels. Standards-setting is an important first step in achieving equity because educators have established expectations for all students. Without resources or opportunities, however, setting high academic standards may pose additional challenges and learning difficulties to these students (Kahle, 1997; Porter, 1995). There is a great concern that “lack of support in reaching high standards will further victimize students already harmed by gross inequities in the educational system” (McLaughlin, Shepard, & O’Day, 1995, p. 68).

Before implementing these standards for all students, it is necessary to critically analyze the standards and science achievement in relation to equity. Stanley and Brickhouse (1994) state, “The definition of what counts as science is at the heart of the curriculum reform debates,” especially as it pertains to equity (p. 389). In this section, two issues are discussed: (a) What is the perspective of equity in science and science achievement in major reform documents? and (b) What are alternative perspectives of equity?

**Perspective of Equity in Major Reform Documents**

Equity is defined in many different ways. These definitions are often inconsistent and even contradictory. Secada (1994) identified six different conceptions of equity among school personnel and speculated even more. These six conceptions of equity include equity as (a) a concern for the whole child, (b) a safety net for individual differences, (c) the same treatment for everyone, (d) compensation for social justice, (e) triage, and (f) the maximum return on a minimal investment. Kahle (1996) arranged these six conceptions of equity in a historical continuum. Based on these previous studies, Lynch (in preparation) identified three definitions of equity: (a) as outputs or results; (b) as inputs, equal opportunities to learn, or equal access; and (c) as fairness and tradeoffs—the middle ground for thoughtful negotiation and decision-making. Based on a theory of social justice for multicultural education (Banks, 1993; Grant & Sleeter, 1986), Rodriguez (1998) defined equity as “the social and institutional process by which individuals can attain empowerment” (p. 591).

Before even considering inputs, process, or outputs in equity, the discussion here involves a more fundamental question about the perspective of science that students are expected to achieve. The definition of “what science is” has major implications for determining the inputs, process, and outputs in equity. Specifically, two issues are addressed. First, what counts as science and what should be taught in school science, as presented in reform documents? Second, to what extent is this perspective of science compatible with ways of knowing by students from diverse backgrounds?

**What counts as science?** Both NSES and Project 2061 emphasize equity along with excellence as a dual goal of science education reform. NSES (NRC, 1996) underscores equity as the first of its four guiding principles: “Science is for all students. This principle is one of equity and excellence” (p. 20, original emphasis). The premise of Project 2061 is equity, as reflected in the title of the document *Science for All Americans.*
In terms of what counts as science and what should be taught in school science, both NSES and Project 2061 define Western science as the proper domain of science. The perspective of Western science is reflected across the categories of science standards in the reform documents, particularly with regard to the history and nature of science. In describing the history of science, *Science for All Americans* (AAAS, 1989) states:

> The recommendations in this chapter focus on the development of science, mathematics, and technology in Western cultures, but not on how that development drew on ideas from earlier Egyptian, Chinese, Greek, and Arabic cultures. The sciences accounted for in this book are largely part of a tradition of thought that happened to develop in Europe during the last 500 years—a tradition to which people from all cultures contribute today. (p. 136)

In describing the contributions of diverse cultures to science and technology, NSES recognizes such contributions in terms of technological inventions to solve human problems and needs, rather than the tradition of thought that defines the nature and practice of science to understand and explain natural phenomena. NSES (NRC, 1996) states historical perspectives in science as follows:

> Modern science began to evolve rapidly in Europe several hundred years ago. During the past two centuries it has contributed significantly to the industrialization of Western and non-Western cultures. However, other, non-European cultures have developed scientific ideas and solved human problems through technology. (p. 201)

NSES and Project 2061 also define the nature of science in the tradition of Western science. The documents stress the scientific world view based on the Western tradition, as opposed to alternative world views. According to these documents, science is a way of knowing that distinguishes itself from other ways of knowing and from other bodies of knowledge (AAAS, 1989, pp. 3-5; NRC, 1996, p. 201). Project 2061 states, “There are many matters that cannot usefully be examined in a scientific way. There are, for instance, beliefs that—by their very nature—cannot be proved or disproved (such as the existence of supernatural powers and beings, or the true purposes of life)” (p. 4). NSES also states, “Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific” (p. 201).

Thus, the history and nature of science is largely defined in the Western science tradition. The contributions of non-Western cultures to science and technology are briefly described in NSES and Project 2061. These contributions are not even mentioned in New Standards, 1996 NAEP, and TIMSS. Based on the history of Western science, the nature of science generally reflects and responds to the norms and practices of the Western tradition. Ogawa (1995) states, “Western modern science has most affinity to the so-called Western culture because the origin of Western modern science was in the Western tradition” (p. 589). The acceptance of Western science in reform documents raises a serious question about equity in science achievement.

**Ways of knowing by diverse students.** All students bring into the science classroom their ways of looking at the world that are formed by their environments and personal experiences (Driver, Asoko, Leach, Mortimer, & Scott, 1994). In considering equity in science achievement, it is important to examine the extent to which the nature of science is compatible or incompatible
with the background knowledge and experiences of students from diverse culture, language, gender, and socioeconomic backgrounds. The emerging, although limited, body of research indicates that students from diverse ethnic, language, and gender backgrounds display ways of knowing and thinking that are incompatible with the nature of science or the way science is taught in school (Atwater, 1994; Baker & Leary, 1995; Barbar, 1993; Calabrese Barton, 1998; Kahle, 1990; Lee & Fradd, 1998; Matthews & Smith, 1994; Rakow & Bermudez, 1993; Rosebery, Warren, & Conant, 1992). A few examples, below, illustrate the differences between the nature of science as defined in content standards and diverse ways of knowing in science.

For example, the emphasis on “scientific inquiry into authentic questions generated from student experiences” (NRC, 1996, p. 31) may pose challenges for students from cultures that respect teachers’ authority of telling and directing students, rather than promoting students’ exploration or alternative solutions (Atwater, 1994; Hodson, 1993; Lee, Fradd, & Sutman, 1995; Ogguniyi, 1988; Prophet & Rowell, 1993). Because inquiry is not part of their cultural experiences, the students need to be explicitly taught how to engage in the inquiry process (Delpit, 1988), as they learn to ask their own questions and find answers on their own. As the students develop abilities to investigate and explore in the science classroom, they may recognize conflicts between their school experiences and cultural expectations for respecting authority. The gap between science knowledge in school and everyday knowledge at home can present learning difficulties for these students.

Cultivation of scientific habits of mind may pose difficulties to students from diverse culture, language, and gender backgrounds. Although some scientific values and attitudes are found in most cultures, others are more characteristic of Western science that promotes a “critical and questioning stance” (Williams, 1994, p. 517), such as being skeptical, making arguments, openly criticizing, thinking independently, and tolerating ambiguity (AAAS, 1989). These values and attitudes may be incongruent with the norms of diverse cultures that favor cooperation, social and emotional support, consensus building, and respect for authority (Atwater, 1994; Hodson, 1993; Lee & Fradd, 1996). The students may have difficulty developing scientific values and attitudes while retaining their cultural norms (Aikenhead, 1996; O’Loughlin, 1992). Faced with such challenge, some students from diverse backgrounds may become alienated from science or even actively resist learning science.

The scientific world view is a topic that has recently become important in science education research. Although the distinction between the scientific world view and alternative views may be relatively straightforward to educated adults, children’s world views involve a complex interaction of personal and supernatural beliefs with scientific understanding (Cobern, 1991; Hewson, 1988; Lee, in press; Ross & Shuell, 1993). High school students from the mainstream reveal alternative views, such as teleology, animism, spiritual forces, and mysticism (Cobern, Gibson, & Underwood, in press; Roth & Lucas, 1997). Alternative world views based on religious beliefs within the Western society also need to be considered (see the debate on evolution and creationism in Cobern, 1994; Jackson, Doster, Meadows, & Wood, 1995; Smith, 1994).

Students from diverse cultures tend to express alternative views more strongly than their counterparts from the mainstream (Allen & Crawley, 1998; Hewson, 1988; Kawagley, Norris-Tull, & Norris-Tull, 1998; Lawrenz & Gray, 1995; Lee, in press). For example, after personal
experiences of a major natural disaster, African American and Hispanic elementary students attributed the cause to societal problems (e.g., race, crime, violence) and spiritual and supernatural forces (e.g., god, devil, or evil spirits) more strongly than their Anglo counterparts, who tended to give explanations as natural phenomena (Lee, in press). Such differences present greater challenges in developing the scientific world view for students from diverse cultures and languages than for mainstream students.

Alternative Perspectives of Equity

Critical analyses of reform documents, particularly NSES and the Project 2061, for equity considerations have been conducted (Eisenhart, Finkel, & Marion, 1996; Lee, 1997; Rodriguez, 1997). Alternative perspectives of science and science achievement have been emerging in multicultural science education, feminism, critical theory, and postmodernism. Scholars in these areas have raised concerns about power relations and the marginalization of females and non-Western students. They also challenge the basic notion of science and science achievement as traditionally defined and argue for more inclusive notions. In this section, two issues are addressed: (a) alternative perspectives of what counts as science and (b) alternative perspectives of ways of knowing by diverse students.

Alternative perspectives of what counts as science. The literature on multicultural science challenges the nature of science as traditionally defined. Ogawa (1995) states, “The science in the slogan ‘science for all’ is still Western modern science, and such a slogan forces everyone to learn Western modern science alone. . . . Why should we teach Western modern science alone and not other sciences?” (p. 584). The issue is clearly presented in the debate on universalism versus multiculturalism epistemology of science (Hodson, 1993; Ogawa, 1995; Matthews, 1994; Siegel, 1997; Stanley & Brickhouse, 1994; Williams, 1994). Stanley and Brickhouse (1994) state, “Science education has remained immune to the multiculturalist critique by appealing to a universalist epistemology; that the culture, gender, race, ethnicity, or sexual orientation of the knower is irrelevant to scientific knowledge” (p. 388). Recently, the multicultural science perspective has questioned the dominance of the Western science and, instead, advocated for inclusion of female and non-Western oriented sciences. Multiculturalist responses to the history and nature of science as traditionally defined and also as presented in reform documents are discussed next.

Multiculturalists emphasize the contributions made by non-Western cultures throughout the history of science. Needham (1981), for example, claims that the Chinese inventions, including paper making, gunpowder, and the navigational compass, are more than mere technologies. He provides evidence that these inventions were “theoretically driven (although its philosophical basis was radically different from that of western science) and involved observation and careful experimentation” (cited in Hodson, 1993, p. 699). In addition to Chinese contributions, others have written about scientific achievements in Islamic (Sardar, 1989), Indian (Kumar & Kenealy, 1992), and African cultures (Bernal, 1987). From a pedagogical stance, recognizing the contributions of other cultures in science and technology can motivate students from diverse backgrounds to participate in these areas.

The nature of science from the multicultural science perspective has gained increasing attention. Based on Cobern’s (1991) comprehensive framework on world views, scholars have identified
alternative views of the world in diverse culture and gender groups that are often incompatible with the scientific world view. The Western science (with its emphasis on explaining, predicting, and controlling nature) and the Western culture (with its emphasis on individuality and independence) come into conflict with fundamental concerns for close, harmonious relationships between humans and nature as well as among individuals or groups in diverse cultures. In addition, diverse cultures tend to believe in supernatural forces, spirits, and myths more strongly than the Western culture. These research results are documented across diverse cultures, including Native Americans in the U.S. (Allen & Crawley, 1998; Hampton, 1991; Kawagley, Norris-Tull, & Norris-Tull, 1998; Pomeroy, 1992; Robbins, 1983), African Americans and Hispanics in the U.S. (Atwater, 1994; Lee, in press), Aboriginal people in Australia (Christie, 1991), Africans (Hewson, 1988; Jegede & Okebukola, 1991, 1992; Lawrenz & Gray, 1995), and Asians (Kawasaki, 1996; Ogawa, 1995). Even within cultural groups, there are gender differences in students’ world views (Jegede & Okebukola, 1992; Lee, in press).

According to the multicultural science perspective, narrow definitions of science based on the Western science perspective is misleading and myopic. Scholars argue that alternative perspectives should also be part of science based on both epistemological validity (Hodson, 1993; Ogawa, 1995; Smolicz & Nunan, 1975) and moral imperative for a just society (Hodson, 1993; Siegel, 1997). Other scholars deny such a claim (Good, 1993; Matthews, 1994; Williams, 1994). Williams (1994) states, “A major goal of science education is to dispel notions of magic and teleology as unscientific. The only proper question for science education is how best to achieve this goal with due regard for student sensibilities in a multicultural setting, not how to incorporate them into a scientific view of the world” (p. 516). Still other scholars propose a balanced perspective of the nature of science (Brickhouse, 1994; Loving, 1997; Stanley & Brickhouse, 1994). Stanley and Brickhouse (1994) state:

The modem science framework is quite powerful when applied in certain situations. But, Western scientific frameworks cannot provide a vantage point beyond other frameworks whereby we could judge, once and for all, what we can know. . . . Feminists and other cultural critics have been much more useful in showing how the perspectives that have been most frequently excluded are those belonging to marginalized groups in our society. Bringing these kinds of perspectives into science is essential. (p. 395)

*Alternative perspectives of ways of knowing by diverse students.* The literature on multicultural science education challenges the ways of knowing or learning opportunities in science as traditionally defined. Atwater (1996) defines multicultural science education as “a field of inquiry with constructs, methodologies, and processes aimed at providing equitable opportunities for all students to learn *quality* science” (p. 822, original emphases; also see Atwater & Riley, 1993). Rodriguez (1998) states, “The basic premise of multiculturalism is that all learners at any grade level must be provided with equitable opportunities for success” (p. 591).

NSES and Project 2061 assume that, given opportunities, all students can learn science as defined in these documents. Not only is the Western science tradition criticized, but lack of a coherent conception of equity or systematic approaches to promote equity is also criticized. In his analysis of NSES, Rodriguez (1997) states, “The invisibility discourse dangerously compromises the well-intended goals of the NRC by not directly addressing the ethnic, socioeconomic, gender, and theoretical issues which influence the teaching and learning of science in today’s schools.”
(p. 19). In a similar manner, Eisenhart, Finkel, and Marion (1996) criticize major reform efforts, including NSES and Project 2061:

We applaud this vision of a scientifically literate citizenry in which many and diverse people act in socially compassionate and democratically responsible ways. However, we are concerned that the means being used to promote this vision are too narrowly focused. While the proposals envision democratic, socially responsible uses of science (hereafter: socially responsible science) and participation by many and diverse people, the existing guidelines do not address obstacles known to interfere with socially responsible applications or widespread interest and access. These limitations of the current implementation plans will, we think, make achievement of “science for all Americans” difficult. (p. 266, original emphasis)

Scholars in multicultural science education, feminism, critical theory, and postmodernism offer alternative perspectives of ways of knowing or learning opportunities for diverse students (Eisenhart, Finkel, & Marion, 1996; also see Calabrese Barton & Osborne, 1998). These perspectives range from conservative, to liberal, and to radical (Keller, 1982). On the conservative end of the spectrum, educators claim that women and minorities will participate in science more actively if they have equal access to positive science experiences already available to male students from Western culture; this claim involves assimilation of women and minorities into the science community without changing existing science systems. Educators with a liberal position argue that the topics, problems, design, and interpretation of scientific inquiry that concern women and minorities should be considered in the sciences. On the radical end of the spectrum, educators advocate that learning science is a political process, in which females and minorities transform the nature of science and pedagogy and establish more equitable power structures than existing science systems of domination and oppression (Calabrese Barton, 1998; Mayberry, 1998). In emphasizing the importance of the lived experience of urban homeless children in science, Calabrese Barton (1998) concludes, “This approach shifts from the traditional paradigm, where science lies at the center, as a target to be reached by students at the margins, to inclusion, where students’ identities remain a central focus that guides pedagogical democratic principles and which transform them so they becomes [sic] an integral part of their lives” (p. 391).

While alternative perspectives argue for redefinition and transformation of science and science education to be more equitable for diverse students, others disagree. Williams (1994) states, “It patronizes ethnic and cultural minority immigrants to attempt to insulate them from exposure to new ideas and influences that they might find disturbing. There is no justification for protecting those who choose to leave their culture and move into a new culture“ (p. 5 17). Still others (Lee & Fradd, 1998; Loving, 1997) propose a balanced perspective; as Loving (1997) states, “This successful balancing act results in acculturating students to mainstream science, while at the same time incorporating the unique perspectives of their prior knowledge and interest” (p. 439).

In summary, what counts as science raises a serious question about equity in science achievement. The Western science tradition as currently practiced in the science community and taught in school science presents “high status knowledge,” and every student should have access to such knowledge. This question of equity presents a challenge. On the one hand, the emphasis on the high status knowledge without consideration of diverse perspectives may make science
less accessible, relevant, or meaningful for some students, particularly those who have traditionally been bypassed in science education including women, minorities, and poor students. On the other hand, the emphasis on diverse perspectives that are culturally and socially significant but marginally important as science topics in the science community and in school science may not promote equitable outcomes. A more balanced perspective recognizes the contributions of diverse cultures in science and technology in defining what counts as science, what should be taught in school science, and how science should be taught.

**Science Content Standards and Equity in Large-Scale Assessment**

At the heart of standards-based reform is the alignment of assessment with content standards (McLaughlin, Shepard, & O’Day, 1995, p. 52; Smith & O’Day, 1991; Webb, 1997). The National Academy of Education panel report states, “The intention of standards-based reform is to set higher standards for all students. . . . New kinds of assessment reflecting these new standards are seen as instrumental in effecting the reform” (McLaughlin, Shepard, & O’Day, 1995, p. 52). Regardless of how challenging and rigorous the content standards are, if all the learning outcomes are not assessed, “teachers and students likely will redefine their expectations for learning science only to the outcomes that are assessed” (NRC, 1996, p. 82). In this section, implications of the aggregated view of science achievement in major reform documents for large-scale assessment are discussed. Two issues are highlighted: (a) alignment of assessment with content standards and (b) equity in standards-based assessment.

**Alignment of Assessment with Content Standards**

Aligning assessment with content standards is a complex task (Webb, 1997). The first step in standards-based assessment is to develop an assessment framework that is derived from content standards. The content standards should be stated as specific, measurable learning outcomes. Then, based on the assessment framework, assessment specifications are designed—“specific aspects, limits, and boundary conditions” on the domains of knowledge and abilities to be assessed (Webb, 1997, p. 37). For 1996 NAEP, NAGB described both the assessment framework (1996) and the assessment specifications (1994). For TIMSS, the assessment framework is described in Robitallie et al. (1993), and the assessment specifications in McKnight, Schmidt and Raizen (1993). In New Standards, a set of performance descriptions for each performance standard serves as assessment specifications (NCEE, 1997a, 1997b, 1997c).

Once assessment frameworks and specifications are designed, the next step in standards-based assessment is to develop assessment activities. A general concern is that science content standards in NSES and Project 2061 are too broad and general to guide assessment activities (Baker, 1997). Even performance standards, such as New Standards, “are not specified well enough for purposes of test development. They do not adequately guide the concrete decisions that need to be made on what is to be measured, how it is to be measured, and what specific tasks and criteria will be used” (Wiley, cited in National Center for Research on Evaluation, Standards, and Student Testing, 1997, p. 5). An extensive knowledge gap exists in specifying the standards to develop assessment activities (Massell, 1994; McLaughlin, Shepard, & O’Day, 1995).

To measure the kinds of knowledge and abilities expected in content standards, appropriate forms of assessment are required. There should be a match between what is to be measured and
how best to measure it. Traditionally, large-scale assessments tend to focus on basic knowledge and skills and use restricted response forms, most commonly the multiple-choice format. In contrast, higher-level thinking and complex abilities in science content standards require new forms of assessment (McLaughlin, Shepard, & O’Day, 1995; National Center for Research on Evaluation, Standards, and Student Testing, 1997). Although the increasing use of alternative assessments indicate current efforts, these assessments present new challenges, as described next.

Large-scale assessments, such as NAEP and TIMSS, have changed significantly in recent years. Traditionally, NAEP science assessments used mostly multiple-choice items with some open-ended items. The Second International Science Study [SISS] used multiple-choice items exclusively (International Association for the Evaluation of Educational Achievement, 1988). In response to the current emphasis on scientific understanding, 1996 NAEP and TIMSS included open-ended, free-response items (including both short-answer and extended-response items) as well as multiple-choice items. In addition, along with the emphasis on scientific investigation and communication, 1996 NAEP for the first time included performance exercises (also called hands-on tasks; O’Sullivan, Reese, & Mazzeo, 1997, p. 42). TIMSS also used performance tasks (also called hands-on activities) with a subsample of students (Martin & Kelly, 1996)

In performance exercises or tasks in 1996 NAEP and TIMSS, students manipulate materials, take measurements, conduct investigations, and communicate their observations and results. Such assessment comes closer to problem solving in real world situations than seeing pictures of an experimental design and answering questions on paper. Despite their critical importance in standards-based assessment, performance measures in large-scale assessments pose limitations. First, because of the need for standardization, performance exercises or tasks are provided for students along with the materials to use, procedures to follow, graphs or tables to report the data, and questions to answer. This standard procedure does not allow students to ask their own questions, design and conduct investigations, and communicate observations or results in their own ways. NAEP cautions that performance tasks often become “follow-the-instructions” questions, rather than higher-level thinking in new contexts or applications to novel situations (NAGB, 1996, pp. 31-33). Second, performance exercises or tasks in 1996 NAEP and TIMSS are administered within limited time in one setting. This constraint does not allow scientific investigations of natural events as an ongoing process. These limitations are inherent in external, large-scale assessments.

New Standards focuses on performance assessments that teachers can use in the classroom and that states and urban school districts can use in systemic reform. As part of science instruction in the classroom, New Standards does not have the constraints of NAEP or TIMSS. The samples of student work included in the New Standards documents (NCEE, 1997a, 1997b, 1997c, 1998) indicate that the assessment system effectively measures many components of science achievement. These components include scientific investigation and communication, as well as understanding of key concepts in three fields of science and of unifying themes across the fields. In contrast, the assessment system rarely addresses technology, science in personal and social perspectives, history and nature of science, and scientific habits of mind.

The discussion here indicates inherent difficulties in the assessment of higher-level thinking and complex abilities in large-scale projects. First, some components of science achievement are difficult to assess. For example, it is difficult to operationalize abstract constructs, such as
scientific habits of mind, in concrete and specific terms. Even after operational definitions are obtained, it is difficult to develop standardized procedures of assessment, such as science in personal and social perspectives. In the process of making these components measurable, assessments may become trivialized and their importance may become minimized.

Second, certain components of science achievement cannot be assessed on demand. For example, scientific investigation involves students asking their own questions and finding answers on their own as an ongoing process. Scientific habits of mind occur naturally as students engage in science tasks. It is difficult to assess students’ scientific investigation or habits of mind on demand within the confines of assessment settings.

Finally, large-scale assessment generally involves written forms. Certain types of knowledge and abilities may require different forms of assessment. For example, assessment of technology (i.e., engineering and design) can be done by constructing and using actual products. Assessment of scientific habits of mind can be done informally as teachers observe cues of students’ dispositions (Webb, 1997, p. 22). Abilities to engage in scientific discourse can be observed as students talk with others in group settings. Although a range of assessment forms can be utilized in classroom assessment, including observations, products, interviews, and portfolios, it is difficult to incorporate these forms and the data they produce in large-scale assessments.

Large-scale assessment projects, especially NAEP and TIMSS, clearly influence state-level assessments (George & Van Horne, 1996; Glaser & Linn, 1997; National Center for Research on Evaluation, Standards, and Student Testing, 1997). NAEP science assessments have been used for state-level results since 1990 (Allen, Swinton, Isham, & Zelenak, 1998; Jones, Mullis, Raizen, Weiss, & Weston, 1992). States also have expressed an interest in creating linkages that allow the comparisons of state assessments with national and state-level NAEP (Glaser & Linn, 1997). Some states incorporate released items from NAEP and TIMSS in their assessment programs, compare their achievement results with those of other states or countries, and analyze their science curricular and teaching practices (Champagne, 1997). As systemic reform continues and is likely to intensify (American Federation of Teachers, 1997; Council of Chief State School Officers, 1997; McLaughlin, Shepard, & O’Day, 1995), the central role of assessment in evaluating the impact of standards-based and systemic reform on student achievement will increase at state and district levels.

Equity in Relation to Standards-Based Assessment

Equity in assessment is concerned with achievement gaps among diverse groups of students in terms of ethnicity, language, gender, and socioeconomic levels. Although science achievement gaps among ethnic and gender groups closed modestly during the past two decades, differences remain significant (see summary results of national databases in Rodriguez, in press).

Rodriguez (in press) points out that, beyond overall achievement results by ethnicity or gender, limited information exists about disaggregation of results for gender-by-ethnic groups (e.g., African American male and female students), or subgroups within an ethnic group (e.g., Mexican Americans, Chicanos/as, Puerto Ricans, and students from various Latin American countries within the generic category of “Hispanics”). He argues that this lack of information fails to
provide important insights about achievement gaps by specific groups. He also argues that
generic ethnic categories may create or reinforce stereotypes about a certain group without
considering differences among subgroups or individuals. For example, the model minority
 stereotype for Asian American students, particularly in mathematics and science, masks great
disparities and challenges facing many students, including Southeast Asian refugees with little
schooling or limited literacy development in their home countries (Lee, 1996, Tobin &
McRobbie, 1996a). In contrast, high-achieving Hispanic students may be at a disadvantage by
lower expectations of teachers and school personnel (Rodriguez, in press).

Inadequate information also exists about specific populations, such as students with disabilities
and limited English proficient students because these students are often exempted from state and
district assessments used for accountability (August & Hakuta, 1997; Lacelle-Peterson & Rivera,
1994). As a result, “leaving these students out of the accountability system provides us with no
indication of the kind or quality of instruction they receive or its effect” (McLaughlin, Shepard,
& O’Day, 1995). Recently, large-scale assessments tend to include more students with
disabilities and limited English proficient students (George & Van Horne, 1996; Glaser & Linn,
1997). For example, on the basis of the inclusion criteria to assess “the achievement of all
students at a given grade or age,” 1996 NAEP included students with disabilities and limited
English proficient students (O’Sullivan, Reese, & Mazzeo, 1997, p. 55, original emphasis).

When students with special needs participate in assessments, accommodations are made to
ensure that the students can demonstrate their knowledge and abilities accurately. For example,
1996 NAEP offered various assessment accommodations for students with disabilities and
limited English proficient students (O’Sullivan, Reese, & Mazzeo, 1997). These
accommodations included one-on-one testing, small group testing, extended time, oral reading of
directions, signing of directions, enlarged versions of test booklets, use of magnifying equipment,
use of an individual to record answers, a Spanish/English glossary of science terms, and bilingual
dictionaries. With certain accommodations (e.g., dictate responses), students with learning
disabilities outscored regular students in statewide performance assessment (Koretz, 1997). The
inclusion of students with special needs in large-scale assessments raises a range of issues, such
as selection criteria, accommodations, validity, comparability of results with accommodations
and without accommodations, and comparisons of NAEP results in its long-term trend design
development and validation of appropriate accommodations is one of the major research
challenges in moving toward the assessment system envisioned for the 21st century” (p. 50).

Although limited English proficient students are more likely to be assessed than students with
disabilities, limited English proficient students are less likely to be given accommodations
Assessments for limited English proficient students need to distinguish their science
achievement, English language proficiency, and general literacy in the first language. To measure
science achievement, assessments need to be done in the language of instruction, with special
assistance in their first language (August & Hakuta, 1997; Fradd & Larrinaga McGee, 1994;
Shaw, 1997). Even using bilingual assessments, it is difficult to distinguish the students’ science
achievement from their English proficiency and general literacy (McLaughlin, Shepard, &
Science assessment between standardized forms and alternative forms of assessment has been a topic of debate (Klein, 1997). A range of positions has been proposed (Fradd & Larrinaga McGee, 1994). Critics of standardized tests charge that these tests are biased in terms of ethnicity, gender, and socioeconomic level (Darling-Hammond, 1994; Garcia & Pearson, 1994; Lacelle-Peterson & Rivera, 1994). They argue that standardized tests generally reflect the mainstream culture, contain content bias, incorporate linguistic and cultural bias, and fail to adequately include diverse student populations in the norming process. Instead, they advocate alternative forms of assessment to promote equity. They claim that alternative assessments provide diverse students with flexible and multiple types of assessment settings, allow the students to participate in assessment activities consistent with their cultural preferences, and enable the students to communicate ideas in multiple ways that may not be available in a particular standard format. The relative equity of standardized tests and alternative assessments, however, indicates mixed results with ethnic, socioeconomic, and gender groups in the case of language arts (Supovitz & Brennan, 1997). Empirical evidence to test various positions is limited (Klein, 1997). In addition, the more flexible and varied assessment activities and settings are, the more difficult it becomes to incorporate them in large-scale assessments.

Science assessment based on rigorous content standards presents both promises and fears for diverse student groups (McLaughlin, Shepard, & O’Day, 1995; Ruiz-Primo & Shavelson, 1996; Shaw, 1997). On the positive side, achievement gaps among ethnic, socioeconomic, and gender groups may narrow because standards-based assessments focus on meaning and relevance, rather than discrete knowledge from textbooks. Also, authentic tasks drawn from the students’ real-life situations motivate and enhance their performance. On the negative side, standards-based assessment may widen the achievement gaps; open-ended tasks and application of knowledge to novel situations may differentially favor students with many opportunities to participate in science-rich environments of home and community over those lacking such opportunities. Assessment tasks based on the content and experiences within the classroom are more fair than those requiring knowledge and abilities in novel situations. Empirical evidence supporting these positions is limited.

Beyond matters of assessment procedures, some scholars address achievement gaps among ethnic and gender groups in terms of social injustice in the education system at large. Rodriguez (in press) explains that contrary to the notion of meritocracy—all students who work hard get proper rewards—the education system is structured in ways to benefit those in power. Unfortunately, “the students most adversely affected by the meritocracy myth come from the fastest growing ethnic groups.” He claims that the meritocracy myth must be exposed and dealt with to promote achievement and participation of minorities and female students in science.
Conclusions and Implications

This paper reviews and analyzes the conceptions of science achievement in major reform documents, including those on content standards (NSES and Project 2061), performance standards (New Standards), and large-scale assessment frameworks (1996 NAEP and TIMSS). Based on the aggregated view of science achievement in these documents, the paper considers implications for equity and assessments in large education systems.

Conclusions

Although there are some notable differences, there is an overall agreement on the conceptions of science achievement among major reform documents (see Table 1). The paper presents an aggregated view of science achievement that is conceived in terms of science content and process (see Table 2).

Although these documents emphasize equity as the key principle, there are tensions and dilemmas in considering how equity is to be achieved with regard to science content standards. In defining what counts as science and what should be taught in school, a tension exists between the Western science tradition as represented in NSES and Project 2061 and alternative perspectives of science and science achievement. Some scholars in multiculturalism, feminism, critical theory, and postmodernism argue that alternative perspectives must become part of a more inclusive and broader definition of what counts as science, what should be taught in school science, and how science should be taught.

The alignment of assessment with content standards is a complex task. Specifying the content standards into assessment frameworks and assessment activities is not straightforward. To measure higher-level thinking and complex abilities emphasized in the content standards, new forms of assessment are required. In large-scale assessments, some components of science achievement present challenges because it is difficult to operationalize, to develop standardized procedures, to administer on-demand assessment, or to use multiple forms of assessment (e.g., observations, interviews, products) in addition to written forms. As a result, these components of science achievement may be left out in assessments. In addition, the relative equity of standardized forms and alternative forms of assessment is under consideration. The equity in assessing rigorous content standards beyond the background knowledge and experiences of students who have limited science opportunities is also under consideration.

New Standards, 1996 NAEP, and TIMSS present significant innovations in large-scale assessments. All three projects developed assessment frameworks that were generally aligned with science content standards. They also used alternative forms of assessment that broke from the restricted multiple-choice format traditionally used in large-scale assessments. The 1996 NAEP and TIMSS used performance tasks and open-ended response items as well as multiple-choice items. New Standards focused specifically on performance assessment. Despite such innovations, these projects also indicate challenges and limitations in assessing high academic standards in large-scale assessments. The innovations and limitations, as discussed in this paper, will provide valuable information for developing large-scale assessments in standards-based and systemic reform (Suter, 1994).
In closure, major reform documents in science education consistently emphasize high achievement for all students. The available knowledge about assessment and equity, however, is limited. The difficulties with educational equity are partially ideological and political concerned with whose science should count and be taught in school science. The difficulties with large-scale assessments are conceptual and practical in terms of how to do the assessment within the confines of assessment settings.

Implications

Standards-based and systemic reform aims at developing a unifying vision of high academic standards for all students. The reform documents are as much political statements as they are educational goals and road maps (Collins, 1998). Tensions and dilemmas abound in conceptualizing and promoting science achievement for all students. For example, NSES emphasizes scientific inquiry as the key in science, whereas Project 2061 underscores scientific understanding. Although the current reform emphasizes a small number of key ideas at greater depth—the principle of “less is more”—the task given to schools and teachers with 855 benchmarks in Project 2061 and 77 sections of learning goals in NSES is still daunting. Thus, even within the traditional science education community, difficult decisions must be made about the scope and priorities of science standards.

Efforts to achieve equity in science education present serious tensions. Based on political and ideological as well as epistemological grounds, some educators argue for a combination of science as traditionally defined and as science presented in reform documents. This argument would force the science community to accept multicultural science and change the fundamental fabric of existing science systems, although it is not yet clear what “multicultural science” would represent. Even if a balanced perspective could be adopted, it would require a substantial redefinition of what science is and how to combine traditional and alternative perspectives of science.

Standards-based assessment also presents tensions. Alignment of assessment with content standards is complicated. Some of key concepts in assessment, including authentic, direct, and performance assessment, are under dispute (Newmann, Brandt, & Wiggins, 1998; Terwilliger, 1997, 1998). The validity and reliability of traditional and alternative assessments is under examination. There is limited empirical evidence about whether standards-based assessment will remedy or exacerbate inequities for students from diverse backgrounds. Even when these conceptual issues are resolved, there is a practical concern that performance assessment is more complex to implement and interpret than paper-and-pencil tests. Performance or hands-on science assessment is also considerably more expensive than paper-and-pencil tests.

Given such tensions and dilemmas, what should educators do? In reality, educators are being required to integrate different, sometimes conflicting or opposing, perspectives in a workable model. For example, because the traditional perspective of science indicates high status knowledge and promotes a set of valuable knowledge and abilities, all students must have access and opportunities to learn. This goal, however, may not be possible for some students, particularly those who have traditionally been underserved, unless science is made meaningful and relevant to their lived experiences based on culture, language, and gender backgrounds. The
relative emphases on the traditional or alternative perspectives may vary depending on science topics, grade levels, student bodies, and other contextual variables.

It is difficult enough to develop reasonably agreed upon conceptions of science achievement, equity, and assessment. It is even more difficult to develop and implement plans that include different perspectives. Beyond ideological and political issues, planning and implementation require practical matters of opportunities and resources. At every step of the way, difficult choices and trade-offs must be made. Without a workable model that integrates different perspectives presented in the literature, the vision of standards-based and systemic reform will remain as rhetoric and not become reality.

The effect of the reform will eventually be tested with teachers and students in the classroom. Although the reform underscores lofty goals of high academic standards for all students, teachers tend to define their teaching roles in terms of cultural myths related to the transmission of knowledge and efficient classroom management, which prove to be obstacles to the reform (Tobin & McRobbie, 1996b). Even after years of reform, teachers often become effective in doing activities and handling materials without understanding why and how such activities and materials promote student learning and achievement (Knapp, 1997). Considering that reform is a long-term process, it is critically important to conceptualize and implement plans that are workable in the real world of classroom instruction. This reality-based, integrative approach to science education can enable students to become “bilingual and bicultural” be able to use the language of science as well as the language of their diverse backgrounds, to cross between the culture of science and the culture of their backgrounds, and to behave competently across settings (Fradd et al., 1997; Lee & Fradd, 1998).
References


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