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UNDERSTANDINGS THROUGH LITERACY: USING THE NATIONAL STANDARDS TO EXAMINE SCIENCE AND MATHEMATICS EDUCATION

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Abstract

Analysis of the national standards documents for science and mathematics was performed using a consensus-building, iterative process designed to both identify those standards that addressed communication (speaking, listening, reading, and writing) and reasoning, and to identify any overt or implied differentiation in the levels of expected performance in meeting those standards. The proportion of each standard's components that directly addressed communication and reasoning was calculated. Total components that composed concepts, principles, and abilities from the *National Science Education Content Standards* were calculated to be 49 of 333 (14%); components from Standards A-F of the *National Science Education Science Teaching Standards* were calculated to be 4 of 28 (14%); the AAAS *Benchmarks for Science Literacy* components of principles and abilities contained 89 of 856 (10%); the *Curriculum and Evaluation Standards for School Mathematics* contained 117 of 260 (44%) components; and, the *Professional Teaching Standards for School Mathematics* had 33 of 142 (23%) of the components. Examined in this paper are the cognitive components of general literacy, the components of general literacy addressed in science and mathematics national standards, the proportions of the national standards documents in science and mathematics that directly address the components of literacy, and the expectations regarding both the levels of science and mathematics literacy and the nature of student responses that can be inferred from the science and mathematics standards documents. Curriculum design and assessment practices will be informed by an approach that produces detailed definitions of science and mathematics literacy from the design of assessment tasks that align with national standards for science and mathematics and the specification of science and mathematics literate responses to the tasks.

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Located within the National Research Center on English Learning and Achievement (NRCELA), the research for the Project on Science and Mathematics Literacy reflects its location. Integration of the research into the cross disciplinary perspectives of the center's work requires that the research be situated within the highly sophisticated perspectives on literacy held in the English education community. While most definitions of science literacy have their foundations in the discipline of science, we are exploring the implications of a definition of science literacy that has its foundation in the abilities to read, write, and reason. These perspectives are by no means contradictory, nor should they be considered competitive, they simply begin from different starting points; one begins with science, the other begins with literacy.

Literacy

Nations of the world communicate the degree to which their citizens are educated through a measure called "literacy rate." Commonly, literacy is defined in terms of its component abilities: reading, writing, listening, and speaking. Definitions of literacy often go beyond the abilities to read, write, listen, and speak to include the ability to reason. Literacy implies the ability to connect ideas coherently with a purpose of mind. Langer, Applebee, & Nystrand (1995) distinguish this "rethinking" or "reformulating" aspect of literacy from the notion of literacy as basic reading and writing skills (p. 3).

In addition to learning the basic literacy skills to "get by," literacy at higher levels involves "the kinds of reflective and analytic activities that support successful learning and communication" and that are the result of "the ability to use language, content, and discourse to extend meaning and knowledge about ideas and experiences" (Langer, Applebee, & Nystrand, 1995, p. 3). The Langer, Applebee, & Nystrand perspective on literacy is socio-cognitive. "Students can gain high literacy because it is an integral part of the cultural way of knowing and doing that underlies how a [school] class operates and work gets done (p. 71). Thus, literacy beyond a basic level involves the ability to use language, content, and thinking from various perspectives in situationally aware, purposeful ways to make sense of experience and gain ideas.

For science, the purposeful thinking that underlies literacy beyond a basic level implies thinking that follows the principles of logic or that produces convincing arguments. Thought and logic in science have a strong association: "Until the twentieth century, logic and the psychology of thought were often considered one and the same. The famous Irish mathematician George Boole (1854) called his book on logical calculus *An Investigation of the Laws of Thought*, and designed it 'in the first place', to investigate the fundamental laws of those operations of mind by which reasoning is performed" (Anderson, 1990, p. 291).

Inferences about a person's abilities to read, listen, speak, and write are based on observations of the person's actions, speech, and products. These products are both verbal, in the form of speech and text, and symbolic, in the form of graphs, equations, diagrams, drawings, and models. Responding to a sign or a verbal command with an action consistent with the message in the command or the sign is an example of an action that signals the ability to listen and to read. A sample of speech or a sample of text are examples of products that signal the abilities to speak and write. Based on observations of actions and products, we make inferences about far more than whether or not a person is minimally literate. We also make judgments about what the person knows and how the person thinks.

Literate behavior and products are the result of mental processes operating on information stored in memory. Reasoning and information are the cognitive components of literacy. Based on analysis of text samples, we make inferences about the quality of a person's reasoning. If we judge that the argument in the text is logical, we conclude that the person reasons logically. If we judge that the information in the text is accurate and congruent with the age and intellectual level of the person who wrote the text, we make assumptions about the quantity, quality, and organization of the information stored in the person's memory. Our judgments about literate behavior are based on internal standards about appropriate levels of literacy. These standards, rather than explicit, are based on the age, background, and education of the individual. Minimal literacy is based on relatively simple criteria, the abilities to sign one's name and read simple text. The criteria that define the degree of literacy or literacy level (i.e., high literacy) are more vague.

Venesky (1990) defines three levels of literacy: learned, competent, and capable of minimal function. Venesky's levels, which apply in both personal and professional contexts, are not distinct but identify points along a continuum. For instance, physicians' medical literacy ranges from capable of minimal function in the profession--no malpractice suits, to learned--the holder of a distinguished chair of medicine. In the personal context, literacy ranges from a capability for minimal function in society--earning a living, voting regularly, attending to health matters, to functioning as a learned participant--a national leader serving as chair of a foundation.

In educational contexts, the literacy continuum is tied to years of education and the developmental level of students. The literacy level expected of students who graduate from high school is lower than that of a two or four year college graduate. In higher education, the expectations for general literacy of students in liberal education programs is essentially uniform across majors or professional education programs. However, the disciplinary or professional literacy expectations differ across majors, across schools within higher education; for instance, in colleges of arts and sciences and professional schools of business, education, or medicine.

There are different types of literacy. Literacy may be ordinary, the literacy applied by ordinary people in the daily activities of life; it may be profession specific, the literacy required for performance in a profession; or, it may be domain specific, the literacy possessed by individuals practicing inquiry in the disciplines. These literacy types are characterized by different information bases, forms of reasoning, methods of professional practice, or modes of inquiry. The domain-literate person has a store of information about the domain: factual information, concepts, principles, laws, modes of reasoning, and methods of inquiry.

Domain-specific, ordinary, and profession-specific types of literacy have elements in common. The domain (biology) or professionally (medicine) literate person is also literate in the ordinary sense. Physicians have some of the domain-specific knowledge and reasoning abilities characteristic of the biologist and chemist. The person who is literate in the ordinary sense may have some domain-specific knowledge and abilities. The contemporary call for science and mathematics literate citizens implies science and mathematics literacy in the ordinary sense; that is, knowing enough science and mathematics to participate actively and intelligently in the work place and in civic affairs. The literacy picture is further complicated by the fact that not only are there different types of literacy, but within each type there are different literacy levels. For instance, ordinary citizens have very different levels of science literacy ranging from little to a level close to that of a practicing scientist. Ordinary citizens also have different levels of mathematics literacy ranging from vocabulary and reasoning related to simple arithmetic to that related to complex axiomatic systems. Science literacy enables individuals to lead fuller lives, to make wise personal decisions, to engage intelligently in public debates about matters related to science, to be economically productive, and to respect the natural world.

National Standards

Science and mathematics education in the United States is in the midst of an unprecedented reform movement. Unprecedented because the movement is driven by national standards developed with support from the federal government. The standards for science and mathematics education are redefining the character of education from kindergarten to the post graduate education of scientists and science teachers. The theme permeating the new vision is science literacy for *all*.

Three professional societies, the National Research Council (NRC), the American Association for the Advancement of Science (AAAS), and the National Council of Teachers of Mathematics (NCTM) have produced national standards for science and mathematics education. The NRC standards are contained in a document titled, *National Science Education Standards* (NRC, 1996). The AAAS standards are contained in a document titled, *Benchmarks for Science Literacy* (AAAS, 1993). The NCTM produced three documents: *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989), *Professional Teaching Standards for*

School Mathematics (NCTM, 1991), and *Assessment Standards for School Mathematics* (NCTM, 1995).

The *National Science Education Standards* document asserts the practical utility and aesthetics of science literacy, describes the characteristics of science literate persons, and informs us that the content standards define science literacy.

> Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities. In the *National Science Education Standards,* the content standards define scientific literacy (NRC, 1996, p. 22).

The attributes of the science literate adult are described in terms of abilities. The science literate person can find or determine answers to questions derived from curiosity about everyday experiences; can describe, explain, and predict natural phenomena; can read with understanding articles about science in the popular press and engage in social conversation about the validity of the conclusions; can identify scientific issues underlying national and local decisions; can express positions that are scientifically and technologically informed; can evaluate the quality of scientific information on the basis of its source and methods used to generate it; can pose and evaluate arguments based on evidence and apply conclusions from such arguments appropriately; and, can appropriately use technical terms (NRS, 1996, p. 22).

The *Benchmarks for Science Literacy* (AAAS, 1993) promote literacy in science, mathematics, and technology:

> In a culture increasingly pervaded by science, mathematics, and technology, science literacy requires understandings and habits of mind that enable citizens to grasp what those enterprises are up to, to make some sense of how the natural and designed worlds work, to think critically and independently, to recognize and weigh alternative explanations of events and design trade-offs, and to deal sensibly with problems that involve evidence, numbers, patterns, logical arguments, and uncertainties (p. XI).

While supportive of a common core of learning in science, mathematics, and technology, the authors of the *Benchmarks for Science Literacy* (AAAS, 1993) have a particular vision for that core and state that the core should "center on science literacy, not on an understanding of each of the separate disciplines" (p. XII). They also state that "the core studies should include connections among science, mathematics, and technology and between those areas and the arts and humanities and the vocational subjects" (p. XII).

Although mathematics literacy is not directly defined within the *Curriculum and Evaluation Standards for School Mathematics,* the authors identify their vision of mathematics literacy as based on a reexamination of educational goals. Historically, societies have established schools to transmit aspects of the culture to the young, and to direct students toward, and provide them with, an opportunity for self-fulfillment. Thus, the goals all schools try to achieve are both a reflection of the needs of society and the needs of students.

Calls for reform in school mathematics suggest that new goals are needed. All industrialized countries have experienced a shift from an industrial to an information society, a shift that has transformed both the aspects of mathematics that are needed to be transmitted to students and the concepts and procedures they must master if they are to be self-fulfilled, productive citizens in the next century. The educational system of the industrial age does not meet the economic needs of today. New social goals for education include 1) mathematically literate workers, 2) lifelong learning, 3) opportunity for all, and 4) an informed electorate (NCTM, 1989, pp. 2-3).

The *Professional Teaching Standards for School Mathematics* (NCTM, 1991) address the teaching environment needed to achieve the vision outlined in the *Curriculum and Evaluation Standards*; however, the nomenclature shifts from a focus on "mathematics literacy" to a focus on "mathematical power." Components of literacy are embedded in the abilities needed to attain mathematical power:

> Mathematical power includes the ability to explore, conjecture, and reason logically; to solve nonroutine problems; to communicate about and through mathematics; and to connect ideas within mathematics and between mathematics and other intellectual activity (NCTM, 1991, p. 1).

Throughout the *Professional Teaching Standards* there is an emphasis on shifting from the notion of classrooms as collections of individuals toward classrooms as mathematical communities engaging in spoken and written discourse about and with mathematics.

The *Assessment Standards for School Mathematics* (NCTM, 1995) continues the perspective established in the *Professional Teaching Standards* of looking at mathematics literacy in terms of mathematical power:

> In the NCTM's Standards documents, the phrase mathematical power has been used to capture the shift in expectations for all students. The shift is toward understanding concepts and skills; drawing on mathematical concepts and skills when confronted with both routine and nonroutine problems; communicating effectively about the strategies, reasoning, and results of mathematical investigations; and becoming confident in using mathematics to make sense of real-life situations. It is away from mastering a large collection of concepts and skills in a particular order (NCTM, 1995, pp. 2-3).

From this perspective, mathematics literacy can be achieved through systematic shifts in a number of aspects of schooling; namely, away from being shown or told, memorizing, and repeating toward investigating, formulating, representing, reasoning, applying a variety of strategies to the solution of problems, and reflecting. Paramount in the *Assessment Standards* is the notion that there may be a cultural aspect to mathematics literacy that allows for and capitalizes on diversity.

What seems to be missing in the definition of science and mathematics literacy in the national standards is a guideline for assessing the details of the communication and reasoning in student explanations. In an effort to look more closely at this gap and to make inferences about the intended levels of students' science and mathematics literate responses, we analyzed some of the standards documents in greater detail. Science and mathematics literacy implies both knowing about scientific and mathematical facts, concepts, principles, laws, theories, and modes of inquiry, as well as the ability to reason scientifically. While we acknowledge the important contribution both of knowing about science to science literacy and of knowing about mathematics to mathematics literacy, our analysis of the standards documents focuses on communication and reasoning.

Assessment

Assessing student achievement has become a central concern in the standards-based reform of education in the United States. Student achievement data are collected for many purposes. Primary among these purposes are tracking the effects of the reform movement, monitoring accountability of local and state education agencies, assigning student grades, and planning curriculum. Our interest in assessment derives not so much from an interest in its political applications or in its use to grade students; rather we see assessment as a powerful tool for defining in measurable terms the desired outcomes of science education and mathematics education and the design of curriculum that enables students to achieve the outcomes (Champagne, 1996). Literacy has performance and cognitive components. Performance components are those observable things the literate person can do. Cognitive components are the mental processes and information underlying performance. The cognitive components are inferred from observations of performance. Consequently, two facets of our approach to the definitions of science and mathematics literacy from a cognitive perspective is via the design of assessment tasks that align with national standards and the specification of science and mathematics literate responses to the tasks. This approach will produce more detailed definitions of science literacy which in turn will inform curriculum design and classroom assessment practices.

METHODOLOGY

The *National Science Education Standards,* the *Benchmarks for Science Literacy,* the *Curriculum and Evaluation Standards for School Mathematics,* and the *Professional Teaching Standards for School Mathematics* were analyzed using a consensus-building iterative process to identify those standards that addressed communication (speaking, listening, reading, and writing) and reasoning. The *National Science Education Standards* and the *Curriculum and Evaluation Standards for School Mathematics,* as the science and mathematics documents with the greatest proportion of standards addressing communication and reasoning, were further analyzed to identify any overt or implied differentiation in the levels of expected performance in meeting the communication and reasoning standards. Our objective was to identify expectations for science and mathematics literacy contained in the standards documents and to calculate the proportion of the total standards that addressed components of literacy. Because each of the documents has a different format, our first challenge was to identify the portions of the documents that we would search.

The analysis of the standards documents was conducted by five individuals. Three of the investigators were primarily mathematics educators, two were primarily science educators. Each of the five individuals independently searched portions of the documents for expectations for student performance related to communication, writing, reading, and reasoning. The results of the independent analyses were compared and discussed by all five investigators. As a result of these discussions, the guidelines for searches were further defined and applied to a second round of analysis of the section. Our search was guided by the following definitions of communication and reasoning: Communication--any means of expressing ideas via the use of language, diagrams, or symbols; Reasoning--the connection of ideas consciously, coherently, and purposively, thinking in logical form, and justifying or explaining.

Expectations for student performance were identified in the standards as being either concepts, principles, or abilities. Only the Unifying Concepts and Processes Standard of the *NSES* Content Standards contained concepts. Other mathematics and science standards contained only principles and abilities. The total number of concepts, principles, and abilities in the standards were determined as follows: Each concept, principle, and ability was identified; each concept, principle, or ability was counted at least once; each principle was counted only once; and, abilities were counted once if they contained a single verb (if the ability contained multiple verbs, the number of verbs determined the count). The same counting procedure was followed to determine the total number of concepts, principles, and abilities related to communication and reasoning.

Three tasks that would satisfy certain science standards were identified and pilot-tested during the 1996-1997 school year. The subjects were students in our university classes: freshmen in chemistry; graduate students in mathematics and science education; and, in-service teachers taking advanced courses. Subjects provided written explanations for one or more of the tasks (given at different times and without time restrictions). The three tasks and the number of respondents for each were: Solvent Task (48 respondents); Graph Analysis Task (14 respondents); and, the Plant in a Jar Task (35 respondents). Each of the three tasks had to be analyzed separately--a process that is still ongoing. Results from only the analysis of the Solvent Task are included in this paper.

RESULTS

The Standards

The standards for content, teaching, professional development, assessment, education programs, and education systems of the NSES were reviewed. Only standards for content and teaching directly addressed communication and reasoning. Standards for assessment, programs, and systems did not contain communication and reasoning expectations for students. However, text elaborating the assessment standards did define criteria that should be used to judge the quality of student performance. For instance, criteria for judging the quality of scientific explanations are contained in the elaborating test for the assessment standards.

The *NSES* Content Standards contain a total of thirteen concepts, two hundred seventy-one principles, and forty-nine abilities. Of the thirteen concepts, two relate to reasoning or communication. Of the two hundred seventy-one principles, nineteen related to reasoning or communication. Of the forty-nine abilities, twenty-eight relate to reasoning or communication. The total of three hundred, thirty-three concepts, principles, and abilities include forty-nine components that relate to communication or reasoning. Thus, fourteen percent of the total number of components in the NSES Content Standards address communication and reasoning. The *NSES* Teaching Standards contain 28 components; four (14%) directly address communication and reasoning expectations for students. This is consistent with the *NSES* Content Standards.

In the AAAS *Benchmarks for Science Literacy*, there are seven hundred sixty-nine principles and eighty-seven abilities. Of the seven hundred sixty-nine principles, fifty-seven relate to reasoning or communication. Of the eighty-seven abilities, thirty-two relate to reasoning and communication. Of the total 856 components, 10% relate to reasoning or communication.

The *Curriculum and Evaluation Standards for School Mathematics* contains seventeen principles and two hundred sixty abilities. Of the seventeen principles, five relate to reasoning or communication. Of the two hundred sixty abilities, one hundred seventeen relate to reasoning or communication. The total of two hundred seventy-seven components includes one hundred twenty-two related to reasoning or communication. This is forty-four percent of the total number of components in the NCTM *Curriculum and Evaluation Standards* .

The *Professional Teaching Standards for School Mathematics* contains one hundred forty-two components. Of these, thirty-three (23%) address communication and reasoning skills expected of students. The majority of these (22) are found in the section on professional standards for teaching mathematics which contains several standards addressing the teacher's role, the student's role, and the tasks involved in classroom discourse. Because, in mathematics, classroom discourse is encouraged to take the form of communication about reasoning and solution strategies, the results are as expected.

<u>The Tasks</u>

The national standards' recommendation for developing the abilities of communication provides an opportunity to better understand the development of scientific reasoning and the degree to which U.S. students are able to reason scientifically. Assessing the ability to communicate requires that students are able to read and understand scientific text and compose scientific arguments and explanations. These written products are windows on the students' reasoning processes.

Conventional analysis of students' responses to assessment tasks focuses on whether an answer is right or wrong. When, for instance, the answer to a question is correct we assume the student reasoned logically using correct information. However, the student might have started with incorrect information and reasoned illogically to come to a correct answer. The only way we can know how a person came to his or her answer to a question is for the person to tell us. That is, ask students to tell us how they came to their answers or to write an explanation of how the answer was arrived at. Thus, our interest is in students' abilities to write and speak about scientific ideas and their applications in daily life.

To develop better understandings of the roles of communication and reasoning in science literacy standards, we have conducted analyses of students' extended responses to questions requiring the application of scientific and mathematical information and principles to practical situations. What follows is an example of our analysis of a task that might be used to assess students' attainment of a standard related to students' ability to develop mathematical models of everyday situations. The standard is: students develop mathematical models of familiar situations and apply the model in other situations. The Solvent Task which follows is an example of a task that would provide evidence that students have met the objective.

The Solvent Task

Solvents are used in many industrial and domestic situations to clean food containers, machines, and tools. The use of solvents, even harmless ones such as water, poses serious environmental problems. The technological problem posed by the use of solvents, is how can the use of solvents be minimized? A solvent-use situation that you have encountered in your daily life is cleaning a paint brush. Use the information below about cleaning a paint brush to develop a mathematical model of paint brush cleaning that you could use to provide advice to industrial and domestic users of solvents about how to minimize their use of solvents while adequately cleaning their machinery, tools, or food containers. Write a memo to an ice cream plant manager, advising her on how the mathematical model you developed informs her about the optimal rinsing of the containers used in making ice cream.

> **Just after finishing a paint job, a painter cleans the excess paint from her brush by scraping it against the side of the paint can. After scraping, the brush contains 4 fluid ounces of paint. The painter dips the brush in a quart of solvent and swirls the brush until the paint and solvent are uniformly mixed. After draining, the brush contains 4 fluid ounces of a mixture which is part paint and part solvent. The process is repeated several times, each time with a fresh quart of solvent.** (Adapted from the Engineering Concepts Curriculum Project, 1970)

We learned from our analysis of college students' answers to this task that the cognitive demands of the solvent task and tasks like it are considerable. Cognitive demands include:

1. The abilities to read, understand, and respond to the requirements of the task;

2. Knowing some basic information, for instance, that there are 32 ounces in a quart, that water is a solvent, that not all solvents are evil-smelling, cancer-causing, volatile liquids like turpentine and benzene;

3. The ability to organize a task requiring successive calculations;

4. Understanding a qualitative model of the process of successive dilution;

5. Understanding proportions;

6. Knowing the difference between the dilution factor and the quantity of solute (paint or ice cream) and solvent (turpentine or water) left on the brush and on the containers;

7. Knowing the characteristics of mathematical models;

8. The ability to make judgments about the application of science and mathematical principles in practical situations;

9. The ability to explain their conclusions to another person.

When science educators engage in the analysis of standards for science literacy using the assessment strategy we have briefly described above, they become more aware of the cognitive demands of the tasks. Furthermore, many contentious issues arise. Some of these issues are discussed below.

Issue 1:

Are the abilities to read and write components of science literacy? Are items that require students to read more than a single statement and to write extended responses fair measures of students' science literacy? Many of the students responding to the solvent tasks were highly critical of the amount of reading required to complete the task. Furthermore, the vast majority of elementary and middle school teachers with whom we have interacted believe that it is unfair to test students' science literacy using exercises requiring much, if any, reading and writing.

Issue 2:

What features should be used to score written responses? Do spelling, punctuation, and grammar count? Is the only correct answer the one the item writer had in mind? Should only the "correctness" of the answer be considered? For instance, if a student's answer is incorrect because of an incorrect assumption or the use of some erroneous information, but the reasoning is sound, should credit for reasoning be given? What do we mean by sound/scientific reasoning anyway? What are the characteristics of proper scientific reasoning?

Issue 3:

Is it fair to test students' ability to develop mathematical models in science classes? Is it fair to test students' ability to write explanations when they have not had the opportunity to learn to write? Is it fair to test students' ability to generalize scientific and mathematical principles to practical situations?

Issue 4:

What are the challenges to testing posed by framing science tasks in practical contexts? Students who gave practical responses to the practical matter (minimizing the use of solvents) and avoided the development of a mathematical model illustrate one of the problems we encounter in testing when science and mathematics are embedded in practical situations. Students bring their practical experience to bear on the question as well as social, economic, and political factors. Is this because they see the questions in their larger context and realize the narrowness of a vision that brings only mathematical and scientific principles to bear on the practical problems?

Responses also illuminate the necessity and value of knowing some very basic information. A number of the students did not know that a quart contains 32 ounces or that water is a solvent (despite the fact that the information is contained in the passage). Interestingly, all of the students who had taken a laboratory course in chemistry should have remembered that the optimal number of rinses is three. A very small number did propose three rinses, but did not indicate that they knew that the number has an empirical basis. One student correctly sketched the concentration of paint versus rinses graphically--a reasonable representation of the correct mathematical model, but provided no clue about the thinking that produced her sketch.

This task also requires students to make practical judgments about how contamination is acceptable in different situations. The graph produced by plotting the quantity of paint remaining on the brush against the number of rinses strongly suggests that after three rinses, further rinsing produces very small changes in the quantity of paint on the brush. In many situations, the quantity of paint remaining after three rinses is sufficiently small. However, the degree of contamination acceptable for a paint brush may not be acceptable for containers in a food processing plant or for medical instruments that cannot be autoclaved.

Issue 5:

What are exercises such as the solvent task testing anyway? Generalizing the information from the mathematical model derived from the paint brush data also presents some interesting conceptual and reasoning issues. The situations are very different. Do the principles that apply in the dissolving of paint in solvent such as turpentine also apply to the dissolving of ice cream in water? Is swishing a brush in a solvent the same as running a solvent over the surface of a container? What effect might the addition of a detergent to the water in the ice cream plant have on the mathematical model? Suppose that the data had been collected using 16 ounces of solvent rather than a quart? What exactly are our expectations for the argument presented in the memo to the ice cream plant manager? For instance, should students be explicit about their assumptions in generalizing the model?

In the context of the solvent task, students can demonstrate their science and mathematical literacy and their ability to communicate and to reason in a variety of ways. A challenge to classroom teachers and test developers alike is how to rate or score written responses that take the potential diversity of student responses into consideration.

SUMMARY & IMPLICATIONS

The national standards were assessed for cognitive components of science and mathematics literacy and then were used to find suitable student assessment tasks. The student explanations from a pilot study using three such assessment tasks are being analyzed and the results from one of the tasks was presented in this paper. Cognitive demands for tasks were identified and issues were presented that should be considered when assessing task explanations. The challenge is to locate or design tasks that are valid, reliable, equitable, feasible, and relevant for classroom assessment.

> The degree to which the students put forth a logical argument to defend their analysis of a physical situation also has important instructional implications. Some investigators have asserted that students' inability to learn physics is simply a function of their inability to think logically. Our analysis of the present data suggests that incorrect conclusions which appear to be the result of illogical reasoning, in fact, may be the result of logical reasoning based on incorrect assumptions or incomplete information. Of theoretical and instructional interest also, is the extent to which students base their interpretation of a physical situation on observation. Our hypothesis is that students' observations are influenced by their conception of the situation, and our analysis provides information that is relevant to this hypothesis (Champagne, Klopfer, Solomon, & Cahn, 1980, p. 15).

During the Fall of 1997, revised and new tasks will be administered to other groups of college students in order to first test the tasks on people who have attained a level of science and mathematics literacy. Once a pool of suitable tasks is available, the assessment will be extended to both younger, less literate groups and to groups possessing high levels of scientific expertise.

The statements in the standards seem clear and reasonable. Proposing exercises that measure their attainment inevitably generate considerable debate among science educators whose individual interpretation of the standards are more often than not quite different. The debate illuminates the challenges that teachers must meet in providing students with sufficient opportunity to meet the standards. We know of no better way of answering questions about the meaning of standards than developing exercises and being explicit about the kinds of responses that provide convincing evidence that students have met the content standards.

Brief Biographies

Audrey B. Champagne is currently Professor of Chemistry and Education at University at Albany and President of the National Association for Research in Science Teaching. Vicky L. Kouba is currently Associate Professor of Education at the University at Albany. They are also co-directors of the Project on Science and Mathematics Literacy, which is a part of the National Research Center on English Learning and Achievement (NRCELA) at the University at Albany, State University of New York. Marlene M. Hurley is a Research Assistant with CELA and a Ph.D. student at the University at Albany. Dedicated to improving the teaching and learning of English and the language arts, CELA provides

information about how best to develop the literacy skills that will heighten student achievement in the content areas, as well as how achievement in the content areas can strengthen literacy skills. CELA is operated by the University at Albany in collaboration with the University of Wisconsin-Madison. Additional partners include the Universities of Oklahoma and Washington. The Center is supported by the U.S. Department of Education's Office of Educational Research and Improvement (Award # R305A60005). However, the views expressed herein are those of the author(s) and do not necessarily represent the views of the department. The Project on Science and Mathematics Literacy brings a cognitive perspective to two practical challenges facing science and mathematics education in the United States. The first is how to assess science and mathematics literacy, and the second is how to contribute to our understanding of the meaning and implications of the trend to integrate mathematics and science in the K-12 curriculum.

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