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ABSTRACT

This interpretive overview of the "Science Report Card" provides a description of the ways in which science can empower and enrich the lives of students. This booklet also contains: (1) statistics which provide a picture of the state of science learning in the United States; (2) specific data that help provide a sense of the status of science learning for at-risk populations; (3) assessment of students' access to the opportunity to learn science; (4) discussion of the relationship between the amount of science instruction and proficiency in science; (5) explanation of science learning in the spirit of science; and (6) discussion of the discrepancy between the picture provided by the data of science learning and the model of science learning based both on research and effective practice. Data for this report were obtained from the National Assessment of Educational Progress (NAEP). (DDR)

THE NATION'S REPORT CARD naep

SCIENCE LEARNING MATTERS

"In limiting opportunities for true science learning, our nation is producing a generation of students who lack the intellectual skills necessary to assess the validity of evidence or the logic of arguments..."

THE SCIENCE REPORT CARD INTERPRETIVE OVERVIEW

EDUCATIONAL TESTING SERVICE

This overview of *The Science Report Card* is based on contributions and comments from the NAEP Interpretive Panel. *The Science Report Card* can be ordered for $14.00, including shipping and handling, from the Nation's Report Card, the National Assessment of Educational Progress (NAEP), at Educational Testing Service, Rosedale Road, Princeton, New Jersey 08541-0001. This interpretive overview, No. 17-S-02, can be ordered free of charge from the address above.

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SCIENCE LEARNING MATTERS

An Overview of *The Science Report Card*

Based on Contributions and Comments from the
NAEP Interpretive Panel

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"The distinctive character of our own time lies in the vast and constantly increasing part which is played by natural knowledge. Not only is our daily life shaped by it, not only does the prosperity of millions . . . depend upon it, but our whole theory of life has long been influenced, consciously or unconsciously, by the general conceptions of the universe, which have been forced upon us by physical science."

—Thomas Henry Huxley, 1880

Science Learning Matters

THE SCIENCE REPORT CARD
INTERPRETIVE OVERVIEW

Science Empowers and Enriches

Huxley's statement on the value of science is even more valid today than when it was written more than one hundred years ago. Then, and increasingly so now, the pervasive influence of science on the quality of our lives makes an understanding of science central to our personal, national, and global welfare. With the accelerating pace of scientific discoveries and technological advances over the last century, knowledge of the methods and products of science has become ever more essential to full participation in contemporary American society. In addition to enhancing the minds and lives of individual citizens, science learning is crucial to the social and economic development of our country. To understand and resolve the increasing number of societal problems related to science and technology — for example, the depletion or pollution of natural resources — our schools must produce a large majority of graduates who are literate about these issues and an increasing percentage of students who are both highly prepared and motivated for advanced careers in science.

From a broader perspective, there is growing concern over our country's future ability to compete in the global economy.[1] A highly technological nation such as ours requires civic and educational leaders whose

[1] Education Commission of the States' Task Force on Education for Economic Growth, *Action for Excellence: A Comprehensive Plan to Improve our Nation's Schools* (Denver, CO: Education Commission of the States, 1983).

understanding of science and technology is sufficient to make decisions based on valid information and rational analysis. Our nation's economic growth and its place in world markets are determined in part by its ability to provide intelligent leadership in technological fields.

The State of Science Learning

It is widely believed that the condition of science education in this country needs improvement, and the results of NAEP's 1986 science assessment do not assuage this concern. In 1983, the National Science Board's Commission on Precollege Education in Mathematics, Science, and Technology described the implications of neglecting science education:

> **Alarming numbers of young Americans are ill-equipped to work in, contribute to, profit from and enjoy our increasingly technological society. Far too many emerge from the nation's elementary and secondary schools with an inadequate grounding in mathematics, science and technology. As a result, they lack sufficient knowledge to acquire the training, skills and understanding that are needed today and will be even more critically needed in the 21st century.**[2]

Since this statement was made, as many as 100 national reports have been issued calling for greater rigor in science education and suggesting numerous reforms. The nation has responded by updating standards for school science programs, strengthening teacher preparation, increasing the use of assessments, stiffening graduation requirements, and implementing a wide variety of research efforts to deepen our understanding of science teaching and learning. Despite these efforts, average science proficiency across the grades remains distressingly low.

[2] National Science Board Commission on Precollege Education in Mathematics, Science, and Technology. *Educating Americans for the 21st Century* (Washington, DC: National Science Foundation, 1983).

Trends for 9-, 13-, and 17-year-olds across five national science assessments conducted by NAEP from 1969 to 1986 reveal a pattern of initial declines followed by subsequent recovery at all three age groups. To date, however, the recoveries have not matched the declines.

- ***At age 17, students' science achievement remains well below that of 1969.*** **Steady declines occurred throughout the 1970s, followed by an upturn in performance between 1982 and 1986.**

- **At ages 9 and 13, the declines were less sizable than those at age 17 and recovery began earlier, in the late 1970s. In 1986, however,** ***average achievement at age 13 remained below that of 1970 and at age 9, simply returned to where it was in the first assessment.***

National expectations are high. Students are expected to complete their high-school studies with sufficient science understanding for assuming their responsibilities as voters and as efficient contributors in the workplace. In addition, school science is expected to prepare adequately for postsecondary science courses those students who are continuing their formal education. Unfortunately, these expectations have not been met. An examination of NAEP trends in science proficiency suggests that a majority of 17-year-olds are poorly equipped for informed citizenship and productive performance in the workplace, let alone postsecondary studies in science.

- **More than half of the nation's 17-year-olds appear to be inadequately prepared either to perform competently jobs that require technical skills or to benefit substantially from specialized on-the-job training. The thinking skills and science knowledge possessed by these high-school students also seem to be inadequate for informed participation in the nation's civic affairs.**

- **Only 7 percent of the nation's 17-year-olds have the prerequisite knowledge and skills thought to be needed to perform well in college-level science courses. Since high-school science proficiency is a good predictor of whether or not a young person will elect to pursue post-secondary studies in science, the probability that many more students will embark on future careers in science is very low.**

These NAEP findings are reinforced by results from the second international science assessment, which revealed that students from the United States — particularly students completing high school — are among the lowest achievers of all participating countries.[3]

- **At grade 5, the U.S. ranked in the middle in science achievement relative to 14 other participating countries.**

- **At grade 9, U.S. students ranked next to last.**

- **In the upper grades of secondary school, "advanced science students" in the U.S. ranked last in Biology and performed behind students from most countries in Chemistry and Physics.**

Given evidence from both the NAEP and international results that our students' deficits increase across the grades, projections for the future do not appear to be bright. The further students progress in school, the greater the discrepancies in their performance relative both to students in other countries and to expectations within this country. Because elementary science instruction tends to be weak, many students — especially those in less affluent schools — are inadequately prepared for middle-school science. The failure they experience in middle school

[3]International Association for the Evaluation of Educational Achievement, *Science Achievement in 17 Countries: A Preliminary Report* (New York, NY: Teachers College, Columbia University, 1988).

may convince these young people that they are incapable of learning science, thus contributing to the low enrollments observed in high-school science courses. Unless conditions in the nation's schools change radically, it is unlikely that today's 9- and 13-year-olds will perform much better as the 17-year-olds of tomorrow.

The Status of Science Learning for "At-Risk" Populations

Students do not all arrive at the kindergarten door with equal opportunities and aspirations. Social and economic realities have begun to have an impact long before that time, and schooling does not serve to eradicate these inequities.

The NAEP data show substantial disparities in science proficiency between groups defined by race/ethnicity and gender.

- **Despite recent gains, the average proficiency of 13- and 17-year-old Black and Hispanic students remains at least four years behind that of their White peers.**

- **Only about 15 percent of the Black and Hispanic 17-year-olds assessed in 1986 demonstrated the ability to analyze scientific procedures and data, compared to nearly one-half of the White students at this age.**

- **While average science proficiency for 9-year-old boys and girls was approximately the same — except in the physical sciences — a performance gap was evident at age 13 and increased by age 17 in most science content areas. At age 17, roughly one-half of the males but only one-third of the females demonstrated the ability to analyze scientific procedures and data.**

- **The marked edge in the physical sciences shown by boys at grade 3 increased at grades 7 and 11; by the eleventh grade, the performance gap in physics was extremely large.**

- **The large difference in science performance by gender cannot be explained by differential course-taking patterns; in some cases, the proficiency gap between high-school-aged males and females actually increased with course-taking.**

Since a higher proportion of Black and Hispanic children than White children come from homes of lower socioeconomic status, disparities in performance attributed to race/ethnicity may be due in large part to differences in such factors as parents' education levels and access to reading and reference materials in the home. In fact, recent research on mathematics achievement shows that when other school and home factors are controlled, students' socioeconomic status accounts for a large part of the performance gap.[4] Economically disadvantaged students are likely to enter school at an educational disadvantage, because they appear to be behind their peers and are therefore placed in remedial classes. The consequence of this early tracking is that many of these students are poorly prepared to pursue higher-level science and mathematics coursework when they get to high school.[5]

In the case of performance disparities between male and female students, there is growing evidence of differential treatment and opportunities in science instruction. Teachers have higher expectations for boys than girls, and ask them higher-level questions.[6] Textbooks may also

[4]Donald Rock et al., *Excellence in High School Education: Cross-Sectional Study, 1972-1980* (Princeton, NJ: Educational Testing Service, 1984).

[5]Jeannie Oakes, *Keeping Track: How Schools Structure Inequality* (New Haven, CT: Yale University Press, 1985).

[6]Marsha Matyas and Jane Kahle, "Equitable Precollege Science and Mathematics: A Discrepancy Model," paper presented at the Workshop on Underrepresentation and Career Differentials of Women in Science and Engineering (Washington, DC: National Academy of Sciences, 1986).

send the message that most of the notable accomplishments in science are attributable to White males. Because there are still relatively few female and minority scientists, students are unlikely to encounter them as role models.

While one would expect in-school experiences to contribute to students' participation and achievement in science, the NAEP data also suggest that some of the factors underlying performance differences may originate outside of the school. This appears to be particularly true for the performance gap by gender. In the 1986 assessment, females were substantially less likely than males to report science-related activities or experiences.

While the NAEP data cannot tell us what causes these differences, there is evidence from other sources that sex- and race-role stereotyping are often major deterrents to the participation of female and minority students in science and science-related activities.[7] For example, parents, peers, the media, teachers, counselors, and curriculum materials may give females and minority students the idea that only certain roles are appropriate for them. Within- and out-of-school experiences appear to reinforce one another in creating and perpetuating differences in achievement.

Research on teaching and learning indicates some approaches that appear promising for improving the participation of females and minorities in science. For example, to counteract the aversion toward physical science that girls seem to develop even before they enter school, elementary science should include an abundance of hands-on activities related to concepts in electricity, magnetism, and other areas, structured so that girls play an active rather than a passive role. In addition, appropriate role models should be provided through interactions with both male and female scientists of various racial/ethnic backgrounds,

[7]Shirley Malcom, "Why Middle School Is Important to Science Equity Concerns," in *Developing Options for Managing the National Science Foundation's Middle School Science Education Programs*, ed. Iris Weiss (Research Triangle Park, NC: Research Triangle Institute, 1986).

both in person and through textbooks, films, and other instructional materials.

Teacher education, both pre-service and in-service, should make teachers aware of the more subtle behaviors that communicate low expectations to particular students, and give them assistance in implementing instructional techniques that are effective with female and minority students, as well as White males. Finally, alternative mechanisms need to be developed to foster the skills that will prepare students for academic sequences in high school rather than curtail their opportunities.

Opportunity to Learn Science

Two distinct aspects of an opportunity to learn are the amount of time spent on instruction and the quality of that time. The first is a necessary but insufficient condition for the second; however, results from the 1986 NAEP science assessment suggest that *neither* condition of the opportunity to learn science is afforded our nation's youth.

- **More than two-thirds of the third-grade teachers responding to NAEP's 1986 teacher questionnaire reported spending 2 hours or less each week on science instruction; many spent more than that amount of time maintaining order and disciplining students in the classroom.**

- **Eleven percent of the third graders assessed in 1986 reported having no science instruction at the time of the assessment; in addition, one-third of the elementary students who were receiving instruction reported spending no time on science homework.**

- **All but 6 percent of the seventh graders reported taking some type of science course in 1986, but enrollment dropped substantially by grade 11. Only 58 per-**

cent of the eleventh-grade students were taking a science course at the time of the assessment.

- **Approximately half of the teachers in grades 7 and 11 reported spending three hours or less providing science instruction each week.**

- **Of the seventh- and eleventh-grade students taking a science class in 1986, 12 to 16 percent reported spending *no time* on science homework each week.**

These findings are corroborated by recent literature in which teachers reported spending only an average of 18 minutes per day on science at grades K-3 and only about 29 minutes per day at grades 4-6. Across these grades, the amount of time spent was greatest for reading, followed by mathematics, then social studies and science — a ranking which had not changed since 1977.[8] Thus, even for those students who are enrolled in science classes, the amount of time actually spent on science learning appears to be minimal.

In addition, very few students in this country take advanced science courses. Preliminary results of a follow-up transcript study of eleventh-grade students participating in the 1986 assessment indicate that while 90 percent of these graduating students had studied at least one year of Biology, only 45 percent had studied one year or more of Chemistry, and 20 percent that amount of Physics. Although these findings represent increases in science course-taking since 1982, enrollments generally remain low from an international perspective. Only about 6 percent of all high-school students in this country take advanced courses in Biology, compared with 45 percent of the students in Finland and 28 percent of the students in English-speaking Canada. Similarly, students studying advanced Chemistry and Physics represent a very small percentage of the total U.S. student population; by comparison, in other

[8] Iris Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education* (Research Triangle Park, NC: Research Triangle Institute, 1987).

countries these students represent as much as one-sixth to one-fourth of the total student population.[9]

The Relationship Between Amount of Science Instruction and Proficiency

A recent report issued by the National Academy of Science Committee on Indicators of Precollege Science and Mathematics Education reviewed the research literature linking instructional time and student learning; it concluded that at both the elementary- and secondary-school level, the amount of time given to studying a subject is correlated with student performance as measured by achievement tests. The report also found that the amount of time spent on homework is correlated with student achievement, and that teachers' attention to homework affects its contribution to performance.[10]

These conclusions are further reinforced by NAEP findings from the 1986 assessment, which suggest positive associations between science proficiency and the amount of time spent in science learning (i.e., through course-taking and homework), particularly among eleventh-grade students. It may be, however, that highly proficient students choose to take more courses or select more challenging courses that require more homework. Further, as previously noted, time spent in science classes *per se* cannot guarantee the quality of that instructional time. Although both common sense and empirical findings indicate that more time spent in science instruction will improve science learning — thus supporting reforms that are targeted toward reducing absenteeism, increasing science course-taking requirements, and assigning more homework — great care must be taken to also address the quality of that instructional time.

[9] International Association for the Evaluation of Educational Achievement, *Science Achievement in 17 Countries: A Preliminary Report* (New York, NY: Teachers College, Columbia University, 1988).

[10] Richard J. Murnane and Senta A. Raizen, eds., *Improving Indicators of the Qualtiy of Science and Mathematics Education in Grades K-12* (Washington, DC: National Academy Press, 1988).

Because educational reforms implemented in the 1980s cannot be expected to have immediate impact and their full effects may not be noticeable for some time, the slight progress evidenced in the NAEP results may portend improvements for the future. It must be recognized, however, that improvements in average performance seen in the 1986 assessment were largely the result of students' increased knowledge *about* science rather than increased skills in scientific reasoning. This finding, coupled with the disappointing state of science education, suggests that current reforms tend to be aimed primarily at the symptoms rather than the disease.[11] What has traditionally been taught in science may be neither sufficient nor appropriate for the demands of the future, necessitating reforms that go beyond increasing students' exposure to science and that center on implementing new goals for improving curriculum and instruction.

Science Learning in the "Spirit of Science"

Embarking on fundamental reforms of science curriculum and instruction requires a reexamination of the conceptual underpinnings of science education. Science educators have maintained that hands-on and laboratory experiences should be an integral part of science instruction, explaining that it is appropriate for science teaching and learning to parallel the methods of investigation used by scientists to understand the natural world.[12]

Results from the 1986 science assessment do indicate a positive relationship between students' use of scientific equipment and their proficiency in the subject, particularly at the eleventh-grade level, but cause-and-effect relationships cannot be addressed by NAEP data. Schools with laboratory facilities and other scientific equipment may be the wealthier schools, populated by advantaged students who tend to

[11] Paul DeHart Hurd, "Perspectives for the Reform of Science Education," *Phi Delta Kappan* (January 1986).

[12] Wayne Welch, "A Science-based Approach to Science Learning," in *Research within Reach: Science Education*, eds. David Holdzkom and Pamela Lutz (Charleston, WV: Appalachia Regional Laboratory, 1984).

perform better in academic assessments. Disciplined research is needed to substantiate the impact of hands-on activities on science proficiency, and the appropriate role of these activities in science instruction.

Findings from the NAEP assessment also suggest positive associations between participatory classroom activities and science proficiency, and between attitudes toward science and students' proficiency in the subject. Again, while the NAEP data are suggestive, they by themselves do not permit the conclusion that more participatory activities or efforts to improve students' views of science will necessarily raise achievement levels for any given student population. Decisions to strengthen science education that may be suggested by the NAEP data must be firmly based on relevant research and experience.

Given these caveats, some aspects of science practice can be used to analyze the nation's science education program and reflect on NAEP findings. What are the features of the scientific enterprise that our science education system might emulate?

ACTIVITIES. Procedures of investigation — such as observation, measurement, experimentation, and communication — allow the scientist to gain an understanding of natural phenomena. In addition, mental processes such as hypothesizing, using inductive and deductive reasoning, extrapolating, synthesizing, and evaluating information are necessary to scientific investigation, as are the less well defined but no less important skills of speculation, intuition, and insight. An effective science learning system would provide students with opportunities to engage in these activities, and encourage science teachers to model them in their classrooms.

BELIEFS AND ASSUMPTIONS. Scientists appear to operate in accordance with a set of beliefs about the natural world that guide their methods of inquiry and the knowledge yielded by these methods. For example, scientists believe a real world exists that can be understood; they assume that nature is not capricious and that events in nature have causes.

Implementing the methods of scientific inquiry yields knowledge about the natural world, contained in the form of facts, concepts, hypotheses, theories, and laws. These structures are characterized in part by scientists' beliefs, making it possible to communicate scientific knowledge, give it logical coherence, offer explanations, and make predictions. Yet another key aspect of the knowledge of science is its tentativeness: Scientists view findings not as final statements but rather as reasonable assertions about some distant, but seldom reached, truth.

CHARACTERISTICS OF SCIENTISTS. Certain personality traits seem to characterize successful scientists, and these may provide additional guidance for determining the features of an effective science education program.[13] Among the salient traits of successful scientists are curiosity, creativity, and dedication. Scientists ask questions about and are sensitive to the world around them. The critical nature of the profession requires a strong belief in one's ability to learn, and an ability to distinguish between productive and unproductive ideas. The joy of discovery is a driving force in scientists' professional lives; they are hungry for knowledge and recognition, and strive to achieve both.

Elements of the Model in Light of NAEP Findings

The "spirit of science" model suggests that the most effective learners are those who are actively engaged in the learning process and accept responsibility for their own learning. In contrast, data from the 1986 NAEP science assessment indicate that by grade 11, almost half of the students have decided not to take any more science courses, few spend time on independent science-related hobbies or activities, and only about half think that what is learned in science class is useful in everyday life. This portrait is indeed far from the model.

[13]W.R. Klemm, ed., *Discovery Processes in Modern Biology* (Huntington, NY: Robert Krieger Publishing Co, 1977).

The brief analysis of the scientific pursuit of learning also suggests the value of providing students with greater opportunities for observing natural phenomena both within and outside the classroom, and engaging them in measuring, experimenting with, and communicating data from the surrounding world. As active rather than passive participants in the learning process, students can strengthen their full range of mental processes, from formulating hypotheses, explaining observations, and interpreting data to other thinking skills used by scientists in their efforts to build understanding.

However, the NAEP data show:

- **Only about one-third of the seventh graders and slightly more than half of the eleventh graders reported that they were asked to hypothesize or interpret data in their science class at least on a weekly basis.**

- **Only 35 percent of the seventh graders and 53 percent of the eleventh graders reported working with other students on science experiments at least on a weekly basis.**

- **Over half of the third graders and more than 80 percent of the seventh and eleventh graders reported *never* going on field trips with their science class.**

- **Sixty percent of the seventh graders and 41 percent of the eleventh graders said they *never* had to write up the results of science experiments.**

- **Only about 46 percent of the teachers of seventh or eleventh grade reported access to a general-purpose laboratory and only 64 percent of the eleventh-grade teachers reported access to a specialized laboratory for use in teaching science.**

A classroom environment that emulates the "spirit" of science is characterized by collaboration between teachers and students to test knowledge that is gained and a willingness to modify this knowledge in light of new evidence. This setting encourages students to wonder about the world around them and actively seek to understand it. It builds their thirst for knowledge and strengthens their sense of responsibility to learn. Teachers provide role models for students and stimulate their curiosity. Yet numerous studies of the last few years — for example, John Goodlad's *A Place Called School* — have indicated that most teaching, including science teaching, is instead dreadfully dull.[14]

For the classroom to mirror the real-world practice of science, the teacher should be an active model, spending less time lecturing and more time engaging students in hands-on activities and asking open-ended questions than do teachers in general.[15] In contrast, students in the 1986 NAEP science assessment reported few opportunities to explore natural phenomena directly or engage in discussions about the limited experiences that they did have. They revealed a preponderance of class time spent listening to teachers' lectures; in addition, limited information on school curriculum suggests that scientific content appears to be largely textbook- and workbook-driven, reflecting little — or not at all — the recent technological advances in the domain of science.

Science Curriculum

To provide curriculum, instruction, and facilities appropriate to the demands of science teaching and learning, it is clear that a number of substantial changes are needed. The need for greater availability of classroom laboratory facilities is undeniable. The 1985-86 National Survey of Science and Mathematics Education found that while most

[14]John Goodlad, *A Place Called School* (New York: McGraw-Hill Book Company, 1984).

[15]Ronald J. Bonnstetter, John E. Penick, and Robert E. Yager, *Teachers in Exemplary Programs: How Do They Compare?* (Washington, DC: National Science Teachers Association, 1983).

teachers believed that laboratory classes were more effective than non-laboratory classes, lectures were reported as their primary teaching technique. However, this paradox may be partially explained by the fact that a substantial percentage of teachers do not have access to adequate laboratories, science equipment, supplies, and other resources needed for teaching science.

Equally or perhaps even more crucial than greater access to laboratory facilities are the more fundamental, but less obvious, changes associated with teaching and curriculum. Cross-cultural studies shed some light on the direction that is needed, revealing significant differences between science curricula in this country and those in Japan, China, East and West Germany, and the Soviet Union.[16] In these five countries, science content is more closely linked to the requirements of modern industrial society, and the instructional approach is to teach an array of disciplines over a period of years, maintaining continuity across the grades. In comparison, the prevailing practice for public school students in the United States is to take one science subject for one academic year and then move to another discipline the following year — sometimes referred to as the "layer-cake curriculum."

Before sweeping changes in curriculum are adopted, research is needed to establish the effects of the content, sequence, and amount of science instruction on students' science learning. Because education is cumulative, perhaps the best way to understand how curriculum and course-taking affect student knowledge and competence in science is to conduct longitudinal studies that follow students through at least one year of science instruction. One difficulty in conducting this type of research, beyond cost, is to describe in sufficient detail the content and other attributes of the science curriculum actually presented to students, beyond the course title and textbook used. By examining important aspects of both the intended and implemented curriculum — and relating these "opportunity to learn" data to students' mathematics

[16]Margrete Klein and F. James Rutherford, eds., *Science Education in Global Perspective: Lessons from Five Countries* (American Association for the Advancement of Science: Selected Symposium Series, No. 100. Boulder, CO: Westview Press, Inc. 1985).

achievement — the Second International Mathematics Study offers a useful model for research in science learning.[17]

Science Instruction

In the ideal science classroom, students would have abundant opportunities to question data as well as experts, to design and conduct real experiments, and to carry their thinking beyond the information given. They would identify their own problems rather than always solving problems presented by tests, teachers, or other authoritative sources. Much of their problem-solving might also be in the form of practical experience. Through these experiences, students would come to realize that knowledge in science is tentative and human-made, that doing science involves trial and error as well as systematic approaches to problems, and that science is something they can do themselves. To provide such instruction, teachers need to be prepared with a keen understanding of the nature of science, rather than just its requisite facts. Like their students, few teachers have had opportunities to conduct real experiments under real conditions; therefore, as a starting point, teacher education should provide opportunities for prospective science teachers to work with students at a variety of grade levels and in a variety of settings. The traditional one-semester methods course required of prospective teachers should give way to two or three semesters of coursework in this area, using video and audio tapes, intense feedback from professionals, and methods instructors who model the types of instruction desired.

At the same time, courses in the history, philosophy, sociology, and applications of science should be required of pre-service science teachers, enabling them to develop a rationale for teaching science that integrates their goals for teaching science and what is known about effective teaching practices, the nature of science, and the ways in

[17]Curtis C. McKnight et al., *The Underachieving Curriculum: Assessing U.S. School Mathematics from an International Perspective* (Champaign, IL: Stipes Publishing Co., 1987).

which children learn — as well as methods of evaluation that are compatible with all of these. Teachers with such a rationale are prepared to be flexible and can integrate research into classroom practice. These teachers approach teaching scientifically and provide models of active inquiry for students. Perhaps teachers with such rationales would rely less on textbooks and would find them more useful as reference materials than as curriculum guides. As a result, students may come to see that science class is a place where the role of student and teacher alike is to raise questions and investigate possible answers and to explore new techniques and methodologies.

Teachers with a new rationale for science instruction would not only be competent and consistent, but also concerned with domains beyond knowledge — including the role of career choice, creativity, attitudes, thinking, application, and communication in science instruction. Students successful in these domains would more closely approach the levels of science literacy called for by virtually all educators concerned with the current state of science education.

Conclusion

Evidence from NAEP and other sources indicates that both the content and structure of our school science curricula are generally incongruent with the ideals of the scientific enterprise. By neglecting the kinds of instructional activities that make purposeful connections between the study and practice of science, we fail to help students understand the true spirit of science, as described in these pages.

In limiting opportunities for true science learning, our nation is producing a generation of students who lack the intellectual skills necessary to assess the validity of evidence or the logic of arguments, and who are misinformed about the nature of scientific endeavors. The NAEP data support a growing body of literature urging fundamental reforms in science education — reforms in which students learn to use the tools of science to better understand the world that surrounds them.

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