National Science Teachers Association

NSTA Position Statement

Beyond 2000—Teachers of Science Speak Out

An NSTA Lead Paper on How All Students Learn Science and the Implications to the Science Education Community

The National Science Teachers Association has a long and rich history of advocating science literacy for all students. In 1964 in "Theory into Action," NSTA stated that literate citizenry in science is achieved through carefully planned kindergarten through grade 12 science programs. This theme continued in the 1980s when NSTA developed position statements on science education and scientific literacy, culminating in 1990 with the lead paper, *Science Teachers Speak Out: The NSTA Lead Paper on Science and Technology Education for the 21st Century*. In 1994, NSTA sponsored the development of the *Handbook of Research on Science Teaching and Learning* in celebration of NSTA's 50th anniversary. And in 1998, the NSTA Board of Directors published a position paper, *The National Science Education Standards: A Vision for the Improvement of Science Teaching and Learning*. The position paper, extensively based on the National Science Education Standards, puts forward the position that "science standards are for all students" and essential for achieving a scientifically literate populace.

As we enter the 21st century, NSTA reaffirms the importance of scientific literacy for ALL students. To achieve scientific literacy for ALL students, NSTA states the following convictions:

- Knowledge of the natural and technological world is changing and expanding rapidly as new knowledge is acquired. What teachers of science must learn about and teach to their students is affected by this changing knowledge.
- The knowledge of how students learn science is changing (Bransford et al., 1999) and supported by Pellegrino (2001). This new knowledge must guide instruction, policies, programs, and practices that affect the development of instructional materials, design of curriculum programs, and programs of assessment in science from preservice throughout their career.
- *National Science Education Standards* (National Research Council [NRC], 1996) describe the essential science content that all students must have the opportunity to learn and that inquiry provides a context within which the content is to be learned.

- The knowledge of how teachers learn science content, how to facilitate student learning, and how to assess student learning should guide the policies, programs, and practices that establish professional development of teachers of science.
- Professional development of teachers of science is a lifelong process requiring the support of an educational system that is also learning and adapting to new research and technology.
- Support for the lifelong professional development of teachers of science requires the existing systems to adapt and change, provide sufficient funding for professional activities, and seek new structures for professional development.

NSTA offers the following in support of these convictions:

Societal Changes

The rapidity and extent of change are two of the most dominant factors of modern society. Individuals will live in a world that is more and more complex and difficult to imagine and predict. Although the future is difficult to predict, we know that the future will include dramatic changes that will profoundly influence schooling, teaching, and learning. Those changes will be based on the increasing complexity of science, technology, and the application of science and technology. These changes require high quality K-16 science teaching.

Scientific Knowledge Is Changing

Scientists agree that the world is in a period of rapid change (Siebert, 2000). Science knowledge has increased exponentially from the 19th century to the 20th century. With the beginning of the 21st century, this knowledge is increasing even more rapidly. This is evidenced by the changes in genetic engineering, computer knowledge, technology, and science applications. In the 1900s, the major task facing scientists was to obtain more data to confirm classical theories (Siebert, 2000). Then came quantum mechanics and new understandings of the nature of matter. Now, with tools such as the Hubble Space Telescope and the technology of genome decoding there is almost no limit to the changes in scientific knowledge.

How Students Learn Science

The knowledge of how students learn science should guide instruction, programs, policies, and practices. Unfortunately, in most cases, school practice is based on an understanding of the learning process that will soon be a century old (Resnick and Hall, 1998). Edward Thorndike, the leading learning theorist in the early 1900s, advanced a model that considered learning as a collection of bonds or links between pairs of external stimuli and an internal mental response. Following this model, learning became a matter of strengthening the bonds through drill and practice. An outgrowth of this model was the frequent testing of many repeated items, each one designed to test the “strength” of a bond.

During the same time period, John Dewey was advocating a very different approach to teaching and learning that placed an emphasis on the process or method of science and learning in general. But through World War II and into the late 1950s, the theory of learning advocated by Thorndike and others was the major influence on education and training in most institutions. In the late 1950s and 1960s, Bruner (1977) and the followers of Piaget reinforced the "child-centered" tenets of Dewey and attempted to counter the drill-and-practice regimen of the Thorndike era. Unfortunately, the debate was often between the so-called process of learning versus the recall of facts.

For the past 30 years or more, a body of cognitive research has accumulated that focuses on the nature of the human processes in thinking and learning. The research supports the Piagetian idea that people of all ages construct their own understandings by processing and acting on their experiences. They do not simply accept and retain the explanations presented to them by the authority figures in their world. Furthermore, research indicates that learning is not a process of recording the input on a blank mental tape but depends on what the person already knows. This research necessitates changes in the ways teachers teach science and the way individuals are prepared for a science teaching career.

What recent research and the subsequent model of learning tells us is that facts alone, even if they can be recalled in a Thorndike-like manner, do not result in the ability to apply information, solve new and complex problems, and retain the knowledge for long periods of time. At the same time, research does not support the purely child-centered approach to learning isolated processes. As Resnick (1998) states, "... facts alone do not constitute true knowledge and thinking power, so thinking processes cannot proceed without something to think about."

Recently the National Research Council (1999) published *How People Learn*, a synthesis of the research on learning. Three of the research findings summarized in the publication have implications for teaching of science:

- Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom. Teachers of science must draw out and work with pre-existing understandings that students bring with them.

- To develop competence in an area of inquiry, students must: (a) have deep foundations of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application. Teachers of science must provide their students with inquiries that mentally and physically engage their students with the content, and evidence for it, in ways that facilitate students' understanding as well as provide opportunities for students to apply and transfer their knowledge to new situations.

- A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them. Teachers of science must stress the skills of reflective thinking and self-assessment and use a variety of formative assessment strategies that provide students with feedback that will guide them in the modification and refinement of their thinking.

What Students of Science Are to Learn and Understand

The National Science Education Standards (*NSES*) (NRC, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) provide a description of the essential science content that all students should have the opportunity to learn, understand, and be able to do. In the first half of the 20th century, the emphasis was on the acquisition of skills, information, and the ability to compute with little attention to transfer or problem solving. The NSES and Benchmarks outline science content and stress the development of understanding the science content through inquiry. This inquiry provides the context that includes the students being engaged in many of the same activities and thinking processes as scientists who are seeking to expand human knowledge of the natural world (NRC, 1999). In the *NSES* the outcomes of science learning contained in the content standards are summarized as the development of the scientifically literate student (NRC, 1996, page 22):

> Scientific Literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.

Assessment as a Component Integral to Learning Science

When the outcomes of learning are clearly specified, as they are in the *NSES*, assessment can and should be used as feedback to improve the learning/teaching process as well as to determine if students are achieving the desired outcomes. A research review by Black and Wiliam (1998) indicates that formative assessment used frequently as feedback to individual students is one of the most effective strategies available to teachers in meeting high standards of student learning. To be effective, formative classroom assessment should be used to:

- diagnose students' pre-existing knowledge;

- assess deep understanding, not superficial knowledge or isolated facts;
- develop students' self-assessment skills;
- provide feedback, not marks or other forms of comparisons among students; and
- support the perspective that ability is not fixed but can be developed and increased.

Summative assessments (large-scale assessment) are a significant part of the educational scene. Such tests should (1) be aligned with the content in the curriculum the students are experiencing, (2) emphasize deep understanding, (3) provide results that can be used as feedback by classroom teachers, and (4) assess the conditions or opportunity to learn as well as student achievement. And in all cases, assessments should be designed to enhance and inform the learning process.

Professional Development for Teachers of Science that Support Learning Science

The knowledge of how to facilitate student learning, how to assess student learning, and how teachers learn science content, should guide the policies, programs, and practices as described by the *NSES* (NRC, 1996). That knowledge must also establish the professional growth of teachers of science as a lifelong process, which is called pedagogical content knowledge (Shulman, 1987).

Professional learning begins with a preservice program where science content courses provide a solid foundation of information and knowledge; education courses provide background in psychological, sociological, and historical perspectives; and specialized science methods courses blend effective pedagogy and science content.

The preservice program must emphasize extensive field experiences that allow future teachers of science to see a master teachers of science effectively use and model pedagogical practices with up-to-date relevant science content. The program also should contain a long-term student teaching experience with a master teacher who models a standards-based approach and understands:

- how to promote learning with understanding,
- how to use students' pre-existing knowledge and beliefs in designing science lessons that cause students to construct new knowledge, and
- how to help students learn to recognize when they understand and when they need more information. The emphasis should be where students are active rather than passive learners (NRC, 1999).

During the early years in a science teaching career, there must be ongoing professional development that facilitates the progression of learning from novice to expert (Berliner, 1988). This ongoing improvement includes increasing science content (Loucks-Horsley, Hewson, Love, and Stiles, 1998) and expanding understanding about how students learn science (Ball, 1996, and Bransford, 1999). Such experiences allow teachers of science to develop new ideas and approaches to be refined and personalized. The support of other teachers can facilitate these new approaches (Plummer and Barrow, 1998; National Commission on Teaching and America's Future, 1997).

Professional development opportunities for experienced teachers of science include (Bransford et al., 1999):

- learning from their own practice (e.g., analysis of a particular strategy via an action research project),
- interacting regularly with other teachers of science,
- continued in-depth study via partnership with area higher education institution(s),
- enrollment in graduate degree program that provides coursework in both science and pedagogy, which refine their abilities to facilitate learning with understanding, etc., and
- outside school activities (such as parenting, coaching, and community youth-related activities).

Teachers of science must listen to their students (Fullan and Hargreaves, 1991). Since we know considerably more today than we did ten years ago about how children learn, teachers of science need to use pedagogical research with the same value they give to new science research. Teachers of science need opportunities to try out new approaches in their classroom and receive feedback as they evaluate the classroom transfer and determine its impact on student learning of science concepts. They need extensive opportunities to interact with one another both personally and through other communication channels (e.g. electronic) as they implement new approaches and listen to their students.

Support for individual personal professional growth for teachers, administrators, support staff, and students give each a sense of value and increasing capacity to contribute to the overall system. Considering the magnitude and complexity of science content knowledge and science pedagogical content knowledge, such support for individual growth is especially important for teachers of science.

Science Curriculum Programs that Support All Students Learning Science

Curriculum programs that are well designed and specify what students learn from kindergarten through grade 12 make a difference in student achievement (Schmidt and Valverde,1999). Effective science programs are multi-year and must include and be based on sound principles of learning and support inquiry-based instruction by teachers of science.

Curriculum analysis from The Third International Mathematics and Science Study indicates that most U.S. curricula lack focus and coherence, two major characteristics of curricula that enhance student achievement (NRC, 1999). Because students' learning is enhanced when their pre-existing knowledge is engaged, the science curriculum should be designed to capitalize on the knowledge that students bring to a new learning task, unit, or course. This can happen only if the curriculum has content coherence within units or courses, during a grade level, and from year to year. Coherence requires that the science concepts build on previous concepts and experiences, and that ideas are connected to one another in one or more story lines that weave through a unit, from unit to unit, and from grade level to grade level.

To provide coherence, the science curriculum program must be designed so that students can take a predictable path through the curriculum for a period of several years. The science curriculum materials must have explicit connections of ideas that students and teachers are aware of and provisions must be made to accommodate students that enter midstream in the coherent sequence or need special help in understanding key ideas as they progress through the science curriculum.

Students developing deep understanding of important concepts depend on coherence. The major concepts and ideas of science must be well understood so that students will be able to connect and apply them in a variety of contexts. To achieve this depth of understanding, the science curriculum needs to also have focus, a characteristic that allows students to spend a considerable amount of time on each topic. A well-focused curriculum can be achieved only if the number of topics is limited and the instructional strategies are designed to (a) present subject matter by using a variety of examples, (b) place it within a larger conceptual framework, and (c) provide multiple opportunities and strategies to retrieve and apply the content.

Systems that Support the Development of Scientific Literacy for All Students

Science learning does not occur in a vacuum but within a rich context of a greater education community. Thus, educating a child requires the efforts of an entire system created for that purpose. Teachers, administrators, support staff, policy makers, parents, the community, and the students themselves comprise this system. They all contribute to the child's learning and must measure their success by the science learned by every child and by how that knowledge will contribute to the success of children beyond school.

In order to provide the needed support, leadership, and coordination for the continuing improvement of science education, K–12 science systems (as defined in the *NSES*) themselves must continually assess their progress. Learning from those assessments, correcting, adjusting, and refining their operations can result in dramatic improvements. Just as teachers must continually learn from the degree of success of their students and refine their own efforts, so must the system learn and respond.

Evidence indicates that with the necessary data, educational systems can and do learn. Thus, a critical requirement for improving K–12 science learning is the presence of a system-wide assessment program that monitors ongoing system improvement and progress. Gathering and using students' achievement of individuals as well as groups for each geographic and demographic grouping can provide a tool for improving all aspects of the system's operation (funding, teacher loads, curriculum, policies, professional development, etc.) New understandings of how children learn science and how professionals learn to facilitate the child's science learning are changing our view of science teaching. The use of large-scale assessment as a tool for improvement, increased attention to how systems learn, and study of how NSTA and other professional organizations can encourage that process may help shift the focus to identifying areas rich in opportunity for improvement and success in science learning.

As we begin the 21st century, change should be particularly evident in science teaching and learning due to the exponential growth of science knowledge and science-related technologies and increasing demand for graduates who can effectively contribute and use these advances in understanding. When viewed along with an apparent decrease in the number of qualified science teachers that will be available to teach a growing population of students, the pressures on science programs and science education become apparent. Consequently, the science programs of educational systems will need special care and support.

—Adopted by the
Board of Directors
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