

# **Standards for Science Teacher Preparation**

**National Science Teachers Association  
in collaboration with the  
Association for the Education of Teachers in Science**

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## 1.0 Standards for Science Teacher Preparation: Content

The program prepares candidates to structure and interpret the concepts, ideas and relationships in science that are needed to advance student learning in the area of licensure as defined by state and national standards developed by the science education community. Content refers to:

- Concepts and principles understood through science.
- Concepts and relationships unifying science domains.
- Processes of investigation in a science discipline.
- Applications of mathematics in science research.

### 1.1 Examples of Indicators

1.1.1 Preservice Level	1.1.2 Induction Level	1.1.3 Professional Level
A. Demonstrates strong and significant understanding of the major concepts in all fields for which licensure is sought, consistent with the National Science Education Standards, recommendations of the NSTA, and an assessment of the needs of teachers at each level of preparation.	A. Exhibits a conceptual understanding of concepts in all fields taught and demonstrates a progressive ability to identify and link major organizing concepts.	A. Presents a strong, flexible understanding of the major conceptual interrelationships in the field, identifies recent significant changes in the field, and applies this understanding to planning and instruction.
B. Demonstrates ability to develop a thematically unified framework of concepts across the traditional disciplines of science in keeping with the National Science Education Standards.	B. Thematically unifies concepts from the different traditional disciplines of science in a relevant and appropriate manner.	B. Regularly unifies science concepts from diverse disciplines of natural science, facilitating development of an interdisciplinary understanding of science.
C. Conducts limited but original research in science, demonstrating the ability to design and conduct open-ended investigations and report results in the context of one or more science disciplines.	C. Significantly incorporates design and use of investigation and problem solving as the context for instruction in the classroom; engages students in research projects.	C. Regularly incorporates, designs and uses investigation and problem solving as the context for instruction in the classroom; engages students in research projects.

1.1.1 Preservice Level	1.1.2 Induction Level	1.1.3 Professional Level
D. Provides evidence of the ability to use mathematics and statistics to analyze and interpret data in the context of science.	D. Uses activities employing mathematics and statistics to develop fundamental concepts in science and to analyze and explain data as appropriate for the teaching field and the level of the student.	D. Actively and regularly employs mathematics and statistics to develop fundamental concepts in science, to analyze and explain data, and to convey the nature of science to students.

## 1.2 Rationale and Discussion

Knowledge is a conceptual model through which the individual makes sense of the world (Sternberg, 1985). Shulman (1986) identifies three dimensions of professional knowledge important to the teacher: content, or subject matter knowledge; pedagogical content knowledge; and curricular knowledge. Content knowledge as defined in this standard consists of the concepts and relationships constructed through professional investigations in the natural sciences, and the processes of scientific investigation.

Constructivism emerged from the realization that pre-existing knowledge influences the way new knowledge is added to the individual's conceptual model, modifying its subsequent meaning (Stahl, 1991). Educators increasingly understand that private knowledge - the true conceptual framework of the individual - may differ considerably from the public knowledge of science. Therefore the goals of formal education have shifted from the relatively straightforward process of transmitting information to the more complex task of facilitating development of a meaningful conceptual framework (Brophy, 1992).

Because young children have less extensive personal models than adults, integration of new knowledge is generally improved when learning is concrete. As children mature, they develop a greater ability to operate in the abstract. However, there is considerable evidence to indicate that concrete learning is present well into the high school years, and possibly into adulthood (Remner, Grant and Sutherland, 1978). The use of models, metaphors and analogies by scientists to concretize new knowledge has been amply demonstrated by Dreistadt (1968) and Leatherdale (1974). The need to relate new knowledge to familiar, and even personal, referents seems inherent in meaningful and creative learning.

These findings have implications for the preparation of science teachers. In science teaching, both at the K-12 and university levels, instructors rely heavily upon the abstract teaching methods of lecture and textbook readings supplemented by verification activities and laboratory demonstrations (Boyer, 1987; Dunkin and Barnes, 1986; Smith and Anderson, 1984). As a result, many students, at all levels, learn science superficially. Stepan et al. (1986) found that although older students can use more science terms than younger students, they may decline in their understanding of fundamental concepts. It appears that new knowledge, if poorly integrated, may actually be counterproductive. Lederman, Gess-Newsome and Latz (1994) found the secondary science teacher candidates they studied lacked a unified, stable knowledge structure in their fields. Mason (1992) found that senior and graduate-level biology majors were often unable to link

concepts accurately when asked to make concept maps in their field. These findings have been supported by many other researchers studying students and beginning teachers in science.

Part of the problem appears to stem from a poor match between learner needs and teaching methodology, especially in the preparation of elementary teachers. Stalheim-Smith and Scharmann (1996) and Stoddart et al. (1993) found that the use of constructivist teaching methodologies and learning cycles—methods often emphasizing concrete learning—can improve the learning of science by candidates in elementary education. A second major problem in many courses taught traditionally is their emphasis on rapidly learning large amounts of unintegrated factual information. Major concepts are poorly delineated from less important concepts, and few concepts are learned in depth. This is in contrast with an approach in which fewer, well-selected integrating concepts are carefully linked to form a framework for further learning. A third problem lies in the division of knowledge, for convenience, into disciplines and fields. Such divisions may constrain the development of linkages among concepts across fields and so inhibit the development of an integrated cognitive model.

Ball and McDiarmid (1991) point out that the outcomes of subject matter learning go beyond the substantive knowledge of the subject usually regarded as content knowledge. Students also develop an image of the subject that frames their dispositions toward it, in keeping with the well-known adage that the medium is the message. Depth of preparation in various areas of content knowledge influences both what the teacher chooses to teach and how he or she chooses to teach it (Carlsen, 1991). In addition, experienced teachers have been shown to differ from scientists in the way they perceive knowledge in the natural sciences, being more likely to interpret its meaning from the perspective of teaching and learning. Therefore it is reasonable to assume that institutions could better prepare teachers by considering the specific needs and interests of teachers when designing their teacher preparation programs.

Many studies, including a 1983 meta-analysis by Druva and Anderson (65 studies), show weak but positive relationships between student achievement in science and the background of the teacher in both science and education coursework (Anderson and Mitchner, 1994). Ferguson and Womack (1993) found in a three-year study that course work in teacher education was a more powerful predictor of teacher effectiveness than measures of content expertise alone. Darling-Hammond (1991) cites several studies demonstrating that teachers admitted to the profession through quick-entry alternative routes had difficulty with pedagogical content knowledge and curriculum development. She also cites several studies supporting the efficacy of subject-specific methods courses for those preparing to teach. Content courses directed toward meeting the specific needs of teachers which are cognizant of their interests and learning styles appear from the literature to be more productive than courses taught traditionally. Such courses usually reflect a constructivist philosophy, focusing on the development of a deeper knowledge of fewer concepts and principles than traditional courses (Hewson and Hewson, 1988).

The development of a clear, consistent integrating framework for science across disciplines is a stated national goal of science education. The National Science Education Standards (National Research Council, 1996), for example, outline a framework of unifying concepts and processes (themes) that underlies its model of knowledge in the natural sciences. These themes include: (a) systems, order and organization; (b) evidence, models and explanation; (c) constancy, change and measurement; (d) evolution and equilibrium; and (e) form and function.

As an example of how these themes integrate subjects, consider how the theme of evolution and equilibrium unifies the concepts of *equilibrium* in chemistry, *homeostasis* in biology, *geochemical processes* in earth science, and *thermodynamics* in physics. In a similar vein the theme systems, order and organization can, for example, unify concepts related to classification and the organization of knowledge in all disciplines. Other major concepts unify studies within more limited fields of study. For example, in biology, concepts such as *adaptation*, *evolution*, and *community* are important unifying themes.

The practice of separating subject matter content from the actions or processes from which it evolves has also been a concern of teacher educators. Many university science programs appear to regard laboratory experiences as ancillary to lecture, useful primarily to validate knowledge delivered by lecture and reading. Teachers who learn science didactically and abstractly cannot be expected to teach children constructively and concretely. Teachers who have never conducted investigations and research are unlikely to model investigative behaviors for their students. Individuals preparing to be teachers should have significant and substantial involvement in laboratory, including active inquiry research that goes beyond traditional validation activities. Investigative projects should require formulation of research questions, development of procedures, implementation, collection and processing of data, and the reporting and defense of results.

Standards of the science education community have generally recognized the need for teachers of science to be competent in mathematics. The preparation required varies across science fields, but generally should be no less for teachers than for others in the field with different career goals. Present NSTA standards recommend at least precalculus for majors in biology, earth/space science and general science, calculus for chemistry and physical sciences, and calculus with differential equations for physics teachers (NSTA, 1996). Direct preparation in basic statistics is also recommended, since the increased emphasis on teaching the processes of science to students entails the ability to lead them in data analysis and interpretation.

### **1.3 Recommendations of the National Science Teachers Association**

The content knowledge of the prospective science teacher is developed primarily in science courses taught by science faculty. Assigning the development of the skills and knowledge required by this standard to one or even several science methods courses is unlikely to produce the depth of understanding needed for effective teaching practice. All science teacher candidates should be provided with a carefully designed, balanced content curriculum leading to a demonstrated knowledge of the concepts and relationships they are preparing to teach.

NSTA believes science content should be specifically selected to meet the needs of the prospective teacher. The rationale for the selection of courses should be clear and justified by contemporary professional goals and practices. It should fit within a state or national framework for science instruction that is consistent with national goals and effective practice as reflected in the science education literature. The general expectations of the NSTA for scope of preparation are as follows:

- For preparation of *elementary and middle-level science specialists*, conceptual content should be balanced among life, earth/space, physical and environmental

- sciences, including natural resources.
- Preparation for teaching *secondary biology* should minimally include thematic concepts and applications of botany, zoology, ecology, physiology, evolution, genetics, cell biology, microbiology, biochemistry and human biology.
- Preparation for teaching *secondary chemistry* should minimally include thematic concepts and major concepts and applications of inorganic, organic, analytical, and physical chemistry and biochemistry.
- Preparation for teaching *secondary earth/space sciences* should minimally include thematic concepts and applications in astronomy, geology, meteorology, oceanography and natural resources.
- Preparation for teaching *secondary physics* should minimally include thematic concepts and major concepts of mechanics, electricity, magnetism, thermodynamics, waves, optics, atomic and nuclear physics, radioactivity, relativity and quantum mechanics.
- Preparation for teaching in a *composite secondary teaching field* (general science, physical science) should be carefully designed to include major and thematic concepts identified for the fields included in the composite and the major concepts of the fields as defined above.
- *Dual field and broad field preparation programs* should ensure adequate scope and knowledge of major concepts across fields unified by thematic concepts. This may require considerable attention to designing courses that are synergistic in developing understanding across fields. Dual field and broad field programs may require more credits in science to achieve the desirable depth if generic science courses make up the program.

To the greatest extent possible, science content should be taught in the context of investigation. Opportunities should be provided for all science teacher candidates to participate in a range of laboratory and field investigations, and to complete one or more projects in which they design and carry out open-ended, inquiry research and report the results. The level of sophistication required may vary with the level of preparation of the candidate and his/her field of licensure. If a candidate is preparing to teach in more than one field, inquiry experiences should be required in all fields, but a research project may only be feasible in one field.

Prospective teachers should be provided with instruction that facilitates the identification and development of concepts that unify the traditional science disciplines. Candidates in one discipline should be able to relate its content to relevant content in other disciplines. The basic themes presented in the National Science Education Standards are highly recommended as organizing concepts. Specific learning opportunities and instruction should be included in the program to develop these interrelationships on a personal and professional level.

Science content should be taught in relation to mathematical applications, particularly in relation to data processing, statistical analysis and interpretation. Effective inquiry depends upon these processes and teachers should be able to analyze data from a variety of sources. For science majors, mathematical competence for the teaching option should be equal to that of any other option. In dual field or broad field programs, mathematical competence should equal that of the

most mathematically demanding science field.

In the best science teacher preparation programs, content is integrated with pedagogy and includes considerable laboratory instruction, including inquiry. There is a clear justified rationale for selection of content based on a careful analysis the needs of practicing teachers and the state and national science education standards. These programs integrate science instruction across fields and prepare candidates with a broad unified science background, in addition to specific preparation. In the best programs, science instruction includes deliberately planned linkages among related concepts in chemistry, physics, biology and the earth/space sciences. Experiences with the analysis and interpretation of data are regularly provided in content courses, as are opportunities for engaging in conceptual development through open-ended inquiry and research in the context of science (rather than science education). The best programs develop a variety of science-related skills, engaging students in active science learning in a variety of contexts. Candidates from these programs have a demonstrably strong conceptual framework in science grounded in experience, are confident in conducting research and inquiry, and can collect and interpret data meaningfully.

#### 1.4 References

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## 2.0 Standards for Science Teacher Preparation: Nature of Science

The program prepares teachers to engage students in activities to define the values, beliefs and assumptions inherent to the creation of scientific knowledge within the scientific community, and contrast science to other ways of knowing. Nature of science refers to:

- Characteristics distinguishing science from other ways of knowing.
- Characteristics distinguishing basic science, applied science and technology.
- Processes and conventions of science as a professional activity.
- Standards defining acceptable evidence and scientific explanation.

### 2.1 Examples of Indicators

2.1.1 Preservice Level	2.1.2 Induction Level	2.1.3 Professional Level
A. Plans activities to convey the nature of basic and applied sciences, including multiple ways to create scientific knowledge, the tentativeness of knowledge, and creativity based on empirical evidence.	A. Uses activities and lessons designed to convey the nature of basic and applied sciences, including multiple ways to create scientific knowledge, the tentativeness of knowledge, and creativity based on empirical evidence.	A. Consistently integrates activities and lessons to convey the nature of basic and applied sciences, including multiple ways to create scientific knowledge, the tentativeness of knowledge, and creativity based on empirical evidence.
B. Compares and contrasts rules of evidence and distinguishes characteristics of knowledge in science to rules and knowledge in other domains.	B. Involves students regularly in comparing and contrasting scientific and nonscientific ways of knowing; integrates criteria of science in investigations and case studies.	B. Designs effective lessons distinguishing science and nonscience and referring to the continuum of criteria for evidence; provides case studies that allow students to analyze knowledge and actions against the tenets of science.
C. Explains and provides examples of conventions for research, evidence and explanation, distinguishing laws, theories and hypotheses.	C. Shows how research questions and design, and data interpretation, are guided by contemporary conventions of science and concepts of the nature of knowledge.	C. Designs lessons showing how research questions and design, and data interpretation, are guided by contemporary conventions of science and concepts of the nature of knowledge.

2.1.1 Preservice Level	2.1.2 Induction Level	2.1.3 Professional Level
D. Provides examples of changes in science knowledge over time, referring to the historical development of foundational concepts in the teaching field.	D. Regularly refers to historical events to illustrate fundamental aspects of the nature of science including the durable but tentative character of knowledge.	D. Systematically involves students in inquiries pertaining to the nature of science including historical and philosophical changes that have shaped subsequent knowledge and the social interpretation of knowledge and events

## 2.2 Rationale and Discussion

Understanding of the nature of science has been an objective of science instruction since at least the first decade of this century (Central Association of Science and Mathematics Teachers, 1907). Sagan (1996) has written on the need for greater science literacy both as a defense against pseudoscience and against unquestioning acceptance of reported research. Recent efforts to reform science education in the United States have strongly emphasized this outcome (AAAS, 1993; NRC, 1996), which is an essential attribute of scientific literacy. While philosophers, historians, scientists, and science educators have not agreed on a single definition of the nature of science (Lederman & Niess, 1997), the concept in the educational literature generally refers to the values and assumptions inherent in the development and interpretation of scientific knowledge (Lederman, 1992).

The academic arguments over the specific values and assumptions of science are probably of little consequence for K-12 students, or most adults. Most science educators would agree that the purpose of science instruction is not to create philosophers or historians of science but to educate individuals who can make valid judgements on the value of knowledge created by science and other ways of knowing. In this respect, it is important for them to be aware that scientific knowledge is tentative, empirically based, culturally embedded, and necessarily incorporates subjectivity, creativity, and inference (Lederman & Niess, 1997).

Despite almost a century of concern, research clearly shows most students and teachers do not adequately understand the nature of science. For example, most teachers and students believe that all scientific investigations adhere to an identical set and sequence of steps known as the scientific method (McComas, 1996) and that theories are simply immature laws (Horner & Rubba, 1979). Students' misconceptions of the nature of science can certainly arise from misinformation from teachers of science. For reasons that are not clear, recent reform efforts have not emphasized staff development on the nature of science, perhaps because of questionable assumptions that teachers currently understand the nature of science, or that the current emphasis on teaching the processes of inquiry will lead by itself to better knowledge of science.

Two assumptions appear to dominate policy and research related to teacher conceptions of the nature of science: that teacher conceptions are directly related to student conceptions, and that teacher conceptions necessarily influence classroom practice (Lederman, 1992). However,

research does not clearly identify a relationship between the teacher's understanding and desire to teach the nature of science and his or her practices in the classroom. Many complex and sometimes competing factors (e.g., time constraints, curriculum constraints, teachers' intentions, teachers' beliefs about students) influence teacher behavior. To be effective in teaching the nature of science, teachers must believe that such instruction is both important and understandable, and then design instruction deliberately to achieve that goal.

The various assumptions and values inherent in scientific knowledge need to be explained if students are to develop adequate understandings of the nature of science. Active inquiry is not enough. Students also must reflect upon their beliefs and actions. They must understand historical and social perspectives on science and scientific knowledge, using case studies and analysis of current issues and problems. The National Science Education Standards (NRC, 1996) identifies the study of issues relating science, technology and societal needs and values in a developmentally appropriate way as an essential part of any effort to teach the nature of science.

### **2.3 Recommendations of the National Science Teachers Association**

All students of science should have a fundamental grasp of the conventions and nature of science and how knowledge created by science differs from other forms of knowledge. Because of this, NSTA strongly recommends that college and university science programs include the nature of science as a thematic strand throughout their science curriculums. Such understanding requires more than participation in science content courses or science methods courses, even those stressing hands-on inquiry, discovery, or research. It requires an active analysis of the nature of knowledge, of the conventions of research and acceptance of findings, the historical evolution of scientific knowledge and an understanding of how humans learn in diverse and complex ways.

All prospective teachers of science should have multiple opportunities to study and analyze literature related to the nature of science, such as *The Demon Haunted World* (Sagan, 1996); *The Game of Science* (McCain & Segal, 1989), *Facts, Fraud and Fantasy* (Goran, 1979) and *The Structure of Scientific Revolutions* (Kuhn, 1962). In addition, they should have the opportunity to analyze, discuss and debate topics and reports in the media related to the nature of science and scientific knowledge in courses and seminars throughout the program, not just in an educational context. Finally, students should engage in active investigation and analysis of the conventions of science as reflected in papers and reports in science, across fields, in order to understand similarities and differences in methods and interpretations in science, and to identify strengths and weaknesses of findings.

The best preparation programs recognize that the nature of science should be understood by all persons who may pursue a career in science. Opportunities to study and understand the nature of science are strongly integrated into science and science education courses and experiences. Teacher candidates in such programs demonstrate a well-developed, integrated understanding of the conventions and nature of science and scientific knowledge, in contrast to other ways of knowing, and can translate that understanding into learning opportunities for students.

## 2.4 References

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### 3.0 Standards for Science Teacher Preparation: Inquiry

The program prepares candidates to engage students regularly and effectively in science inquiry and facilitate understanding of the role inquiry plays in the development of scientific knowledge.

Inquiry refers to:

- Questioning and formulating solvable problems.
- Reflecting on, and constructing, knowledge from data.
- Collaborating and exchanging information while seeking solutions.
- Developing concepts and relationships from empirical experience.

#### 3.1 Examples of Indicators

3.1.1 Preservice Level	3.1.2 Induction Level	3.1.3 Professional Level
A. Plans and implements data-based activities requiring students to reflect upon their findings, make inferences, and link new ideas to preexisting knowledge.	A. Regularly requires students to collect, reflect upon and interpret data, to report the results of their work, and to identify new problems for investigation.	A. Consistently engages students in critical discussion about the results of their inquiry, interpretations of their results, the implications of their conclusions and possible new problems.
B. Plans and implements activities with different structures for inquiry including inductive (exploratory), correlational and deductive (experimental) studies.	B. Involves students in diverse investigations, analysis of investigative structures and discussion of criteria for analyzing outcomes.	B. Systematically integrates investigations with different formats into classroom work, and relates student work to research traditions that typify the various sciences.
C. Uses questions to encourage inquiry and probe for divergent student responses, encouraging student questions and responding with questions when appropriate.	C. Regularly uses divergent and stimulating questioning to define problems and stimulate reflection; leads students to develop questions appropriate for inquiry in a given area.	C. Skillfully facilitates classroom discourse through questioning, reflecting on, and critically analyzing ideas, leading students toward a deeper understanding of the inquiry process itself. Uses questions to define problems and potential solutions.

3.1.1 Preservice Level	3.1.2 Induction Level	3.1.3 Professional Level
D. Encourages productive peer interactions and plans both individual and small group activities to facilitate inquiry.	D. Systematically provides students with opportunities to engage in inquiry with peers using a variety of formats.	D. Skillfully meshes opportunities for science-related inquiry with critical reflection on the role of the individual as an inquirer in a collective context.

### 3.2 Rationale and Discussion

Understanding the process of inquiry as it occurs in a classroom is a complex task. Inquiry cannot be reduced to a set of steps called "the scientific method" any more than chess can be reduced to an algorithmic set of moves based on a few rules. Specific processes of inquiry (like chess moves) must be taught and understood, but the reason for engaging students in inquiry goes beyond the development of isolated skills to the inculcation of an approach or attitude toward engagement with the world. John Dewey (1958) described inquiry as a dialectical relationship between the inquirer and the inquired. Evelyn Keller (1985) described this relationship as "dynamic objectivity." Research on teaching through inquiry reflects the dynamic and multifaceted nature of this construct.

Inquiry involves the development and use of higher-order thinking to address open-ended problems. Resnick (1987) describes higher order thinking as nonalgorithmic and complex. The path to a solution is not discernible from a single vantage point. Multiple solutions are possible, and the inquirer may have to use multiple, sometimes conflicting, criteria to evaluate his or her options. Inquiry is characterized by a degree of uncertainty about outcomes. True inquiry ends with an elaboration and judgement that depends upon the previous reasoning process.

Traditionally, critical thinking has been embedded in the application of various science processes. Schwab (1962), for example, wanted instructional labs to offer opportunities for miniature scientific investigations. To that end, he proposed that teachers present lab problems at three levels for the purpose of developing an orientation to inquiry. At the first level, teachers present problems not discussed in the text, with descriptions of different ways to approach the solution. At the second level, teachers pose problems without methodological suggestions. At the third level, teachers present phenomena designed to stimulate problem identification. Each level requires more facility in using process skills than the previous level.

Trowbridge and Bybee (1990) also discuss three levels inquiry, beginning with *discovery learning*, in which the teacher sets up the problem and processes but allows the students to identify alternative outcomes. The next level of complexity is *guided inquiry*, in which the teacher poses the problem and the students determine both processes and solutions. The third, and most demanding level is *open inquiry*, in which the teacher merely provides the context for solving problems that students then identify and solve.

Questions that promote inquiry and lead to conceptual discussion are important for the success of inquiry teaching and learning (Dantonio, 1987). Since the purpose of inquiry is to lead

students to construct their own knowledge, questioning is an important skill. Rowe (1973) examined the verbal behavior of teachers while they were engaging students in activities emphasizing science processes. Her work showed that high levels of teacher sanctions during classroom interactions were counterproductive, leading students to respond to questions to receive teacher rewards rather than to further the classroom investigation. She identified wait-time as a powerful influence on the length, frequency, and level of student responses, both for the teacher and students. Tobin (1987) reviewed work on wait-time over a twenty-year period and found similar results.

In the 1980's the focus of research shifted to children's intuitive ideas in science (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). The importance of the prior cognitive states of the learner, including specific preconceptions about the natural world, led to a reconsideration of the context and purposes of inquiry (Roth, Anderson, & Smith, 1987). Many scholars abandoned the view that inquiry processes and problem solving skills can be learned outside the context of a specific conceptual problem (Millar & Driver, 1987). This line of research led to the development of mediated forms of inquiry, in which the role of the teacher is to elicit students' existing science knowledge, introduce new ideas in the context of hands-on/minds-on activities, and modify learners' ideas towards accepted scientific concepts (Driver, Asoko, Mortimer, & Leach, 1995; Roth, Anderson & Smith, 1987).

More recently, inquiry has been viewed as having a discursive and relational dimension (Tobin, et al., 1997; Klaassen, et al., 1996) that complements the dimensions of critical thinking and individual skill with science processes. Studies of small group interactions have revealed the power of verbal expression and social interaction to promote student engagement. Teachers use small group interaction to stimulate discussion, increase engagement with materials, distribute responsibility for functions of activities, and distribute expertise around the class. These actions are particularly common in laboratory settings or during hands-on activities in science. Student understanding improves when small groups are structured through assigned roles and scripts for reviewing, rehearsing, and discussing results. (Cohen, 1994).

These effects most likely result from the increased engagement and higher level of discourse among all students resulting from the assigned roles of particular students. However, the teacher who provides too much structure for a task that is, by design, ill-structured may defeat the purpose of inquiry. Cohen (1994) stated a subtle but important dilemma for teachers that has implications for conducting small group instruction in science: If teachers do nothing but supply the task, the students may focus on the mundane or concrete features of the problem without exploring its more abstract and, presumably, more meaningful aspects. If teachers do too much by assigning roles and responsibilities, they may destroy opportunities for students to express novel approaches or ideas.

It is important to note in closing that inquiry-based instruction can have two meanings in practice. Inquiry-oriented instruction can mean teaching about the nature and processes of scientific inquiry, being in that sense a teaching outcome. Alternatively, it can mean that students learn science concepts by using the processes of scientific inquiry. In this sense it is a means to achieve an end. Teachers are more likely to use didactic teaching methods when teaching *about* inquiry by introducing key terms and providing guided practice. The application of inquiry as a teaching method is more likely to be indirect, with the teacher asking more open-ended questions and stimulating more student-to-student discussion (Brophy & Good, 1986).

### **3.3 Recommendations of the National Science Teachers Association**

At the heart of inquiry is the ability to ask questions and identify solvable problems. Science education programs at the college and university level have traditionally focused more on the acquisition of content than on developing skills in questioning and problems-solving. Students at the graduate level often find their hardest task to be the identification of a researchable question for their theses and dissertations.

Students in science should engage in inquiry early in their science programs and should continue to inquire throughout their preparation. Having achieved a high level of comfort with inquiry in this way, students preparing to be science teachers or specialists should face only the task of learning how to adapt inquiry for children.

The abilities to listen and to ask effective questions during teaching are skills that are not easy for most people to master. Effective listening and questioning skills are important to successful teaching in general and need not be confined to science methods instruction. In fact, as for inquiry per se, core preparation in listening and questioning skills before science-specific preparation might be the most effective and efficient approach to developing these skills. However, the ability to ask questions that are consistent with the conventions and processes of science must be developed specifically.

Because of the importance of questioning for inquiry, students throughout their early field experiences and student teaching should be highly sensitive to their questioning behavior. They should regularly analyze their own teaching to appropriately determine their strengths and weaknesses in questioning. Peer teaching may be useful but in a limited way, since adults may find it difficult to play the role of children effectively. Individuals preparing to be teachers should have as much experience as possible working with children. Beyond reactions from observers, self-analysis through audiotapes or videotapes including analysis of questioning behavior is highly recommended.

Inquiry demands skill in the analysis of data and assessment of results to reach reasonable and valid conclusions. As discussed in an earlier standard, students of science should be provided with regular opportunities for data analysis during their content preparation. They should acquire a reasonable level of proficiency in collecting and analyzing data in various formats (open and closed ended), and should be able to use scientific criteria to distinguish valid from invalid conclusions. Effective teachers can adapt teaching activities to create opportunities for inquiry from stock activities that are not focused on inquiry.

Since the social, collaborative nature of inquiry is important, students in science teacher preparation programs should be provided with opportunities to work together and apart. Strategies for group work, including rules to regulate work within project teams, should be part of instruction both in science course work and in education. Students entering teaching should provide evidence of effectiveness in organizing and working with inquiry groups.

Field experiences for prospective teachers should be broad. Programs should require evidence that their candidates can make good judgements regarding the capability of learners, and employ strategies for discovery learning, guided inquiry and open inquiry according to the experience of the learners and the context of the classroom.

The best teacher education programs exhibit strong integration of science with education. Content courses include opportunities for inquiry and regularly require critical thinking and the

identification of researchable questions at an appropriate level. Data analysis is regularly required as part of the process of learning science rather than in support of the learning of content or in occasional laboratory activities. Science education courses and experiences with children document that candidates go beyond the mechanistic learning of the processes of science to a more holistic development of attitudes and disposition toward inquiry.

### 3.4 References

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#### 4.0 Standards for Science Teacher Preparation: Context of Science

The program prepares candidates to relate science to the daily lives and interests of students and to a larger framework of human endeavor and understanding. The context of science refers to:

- Relationships among systems of human endeavor including science and technology.
- Relationships among scientific, technological, personal, social and cultural values.
- Relevance and importance of science to the personal lives of students.

#### 4.1 Examples of Indicators

4.1.1 Preservice Level	4.1.2 Induction Level	4.1.3 Professional Level
A. Engages students in activities and projects in which they examine important social or technological issues related their discipline(s)	A. Regularly engages students in examination of local issues related to applications of scientific and technological knowledge.	A. Makes substantial and continual use of local and national problems, issues, and concerns as a context for teaching scientific and technological concepts and processes.
B. Analyzes values and processes of decision-making about science and technological issues and applications.	B. Engages students in discussions of how values affect scientific knowledge and its applications in technology and society.	B. Integrates discussion of value relationships among science, technology, the individual, and society to form thematic strands that connect concepts throughout the course.
C. Relates science to the personal lives and interests of students, to potential careers, and to knowledge in other domains.	C. Personalizes science where appropriate and works with teachers from other fields, including social science and technology education to incorporate interdisciplinary activities into instruction.	C. Shows skill in creating a context for science which includes the students' personal worlds and knowledge from other fields to create a comprehensive educational framework for learning.

#### 4.2 Rationale and Discussion

Nearly fifty years ago Ralph Tyler (1949) emphasized the importance of paying attention to students' interests when building educational programs. In so doing, he took a stance opposing the traditional goals and curriculum resources that experts had used to build science programs. The tradition of science education in the United States can be described as one of elitism, with the goal of preparation for college dominating all others. Tyler (1949) observed "It seems quite clear that the Committee of Ten thought it was answering the question: What should be the elementary

instruction for students who are later to carry on much more advanced work in the field?" (p. 26). He argued that subject matter specialists, instead, should seek to answer an alternative question: "What can your subject contribute to the education of young people who are not going to be specialists in your field; what can your subject contribute to the layman, the garden variety of citizen?" (Tyler, 1949, p. 26).

We have come a long way since Tyler wrote *Basic Principles of Curriculum and Instruction* to explicate a framework for examining curriculum and instruction. Consider, for example, the "Call to Action" of the *National Science Education Standards*, in which Richard Klausner, Chairperson of the National Committee on Science Education Standards and Assessment, and Bruce Alberts, President of the National Academy of Sciences, assert: "This nation has established as a goal that all students should achieve scientific literacy" (1996, p. ix). The foundation for their belief is that school science, taught under the guidance of the *National Science Education Standards* (NRC, 1996), can provide important skills to all students—skills that will keep America competitive in the global marketplace and help students, as citizens, lead satisfying, productive lives in a highly technological democratic society.

Science teacher education is a critical component of the ongoing effort to develop a nation with scientifically literate citizens. An important basic function of science teacher education is to prepare teachers to relate science and technology meaningfully to the local community, to the daily lives of students, and to broader societal issues. As we view the horizon of the twenty-first century, science teacher educators must consider both Tyler's wisdom and Klausner's and Albert's calls to action. Teachers must no longer treat K-12 education solely as preparation for the university.

A metaphor that embodies the importance of teaching science in context is worth considering. To begin, list the possible adjectives that might describe the common house cat. The list could include terms such as curious, independent, smart, ornery, playful, mean, and quiet—the same adjectives teachers might use to describe children. Now consider how to get a cat out from under a sofa. One way is to reach under the sofa, find an appendage, and pull the cat out. Generally a cat thus removed becomes highly irritated and uncooperative.

A second approach is to drag a length of string across the floor in front of the sofa. The average cat emerges quickly, full of interest, curiosity, anticipation, and even enthusiasm. The point of the metaphor is that we are more likely to achieve positive results if we present science to our students in the same way we present the string to the cat. The string represents the social context of the science curriculum, which relates to the daily lives and interests of students.

This is not a metaphor without grounding in theory and research. If knowledge is a conceptual model that individuals use to make sense of the world (Sternberg, 1985), constructivist epistemology holds that world is the experiential construct of individuals and groups where learners actively build rather than passively receive their models (Staver, 1994). Piaget's theory (e.g., Bybee & Sund, 1982) reminds us that developmental considerations stand paramount in the teaching of science, with young children needing—not just preferring—concrete learning experiences. Even high school and college students vary extensively in their capacity to think abstractly (e.g. Staver & Pascarella, 1984), and therefore can benefit from concrete learning experiences.

Curriculum developers in science education have long advocated concrete learning experiences, and the National Science Foundation has long supported the development of

appropriate exemplary curricula. Presently, several science curricula are available which emphasize science in students' daily lives and broader community and societal issues. *Chemistry in the Community* (American Chemical Society, 1988) and *Biology: A Community Context* (Leonard & Penick, 1998) are two examples. They engage student interests through community contexts while introducing them to substantive chemistry and biology. *Biology: A Human Approach* (BSCS, 1997) places emphasis on connections between students' lives and biological concepts, and on student designed investigations. On a broader level, the science-technology-society movement (Harms & Yager, 1981; Yager, 1996) illustrates an emerging momentum of teaching and learning science in context. With respect to curriculum reform and public understanding of science, several recent publications (Bybee, 1993; Bybee & McInerney, 1995; Lewenstein, 1992) point out the importance of connecting science with students, the public, and society.

#### **4.3 Recommendations of the National Science Teachers Association**

The context of science is closely related to its perceived value and relevance, yet universities commonly isolate the content of science courses from meaningful contexts. This may reflect the view that knowledge is meaningful unto itself, but a more practical reason for abstraction may be that many scientists learned their subject without applied contexts, pursuing research without concern for the applications of their work. They may not be aware of broader applications of work in their field, or its relationship to the needs and values of others. Whatever the reasons, over a decade of reviews of science teacher education programs by NSTA shows that many courses deal poorly with applications, related social issues and values (Gilbert, personal communication).

NSTA recommends that science preparation programs pay more attention to the learning of science in social and technological contexts. Seminars or capstone experiences in which students study the nature of science and its social context in depth might be valuable. Options also include field trips, internships, and arranged visits to industries, businesses and institutions that engage in scientific or technological research in their field, courses from applied fields such as agriculture, nursing, or engineering, and joint study opportunities with teacher candidates in technology education or social studies.

Applications of science are different from issues and values. Issues and values may be most effective if they are presented and discussed in the context of the science preparation to which they most relate. Studying values and issues related to the detection and prevention of AIDS is more likely to be effective as part of a course on epidemiology than similar study as an exercise in a science methods course. Teaching value-analysis and decision-making skills may initially prove problematic where science instructors are themselves unfamiliar with these skills. Professional development of university faculty, both in science and education, will most likely be needed if these skills are to become a significant part of teacher preparation.

The best science teacher preparation programs ensure that their graduates can relate science to applications in the community and in the lives of the students they teach. They provide opportunities for students to understand how the science they study is applied to meet human needs in medicine, business and industry. They provide for study and discussions of issues and values along with content preparation and simultaneously engage students in structured decision-making and values-analysis. The curriculum, overall, is concerned with the integration of issues

into the curriculum and projects required to address them. Candidates for teaching demonstrate the ability to use common sources of information (newspapers, magazines, televised reports) to relate their science instruction to contemporary issues and events. They comfortably conduct discussions relating to values and issues and implement science-related inquiries that relate the content of their science to the needs and interests of their students.

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## 5.0 Standards for Science Teacher Preparation: Skills of Teaching

The program prepares candidates to create a community of diverse student learners who can construct meaning from science experiences and possess a disposition for further inquiry and learning. Skills of Teaching refers to:

- Science teaching actions, strategies and methodologies.
- Interactions with students that promote learning and achievement.
- Effective organization of classroom experiences.
- Use of advanced technology to extend and enhance learning.
- Use of prior conceptions and student interests to promote new learning.

### 5.1 Examples of Indicators

5.1.1 Preservice Level	5.1.2 Induction Level	5.1.3 Professional Level
A. Plans and incorporates science teaching strategies appropriate for learners with diverse backgrounds and learning styles.	A. Plans for and regularly includes alternative activities to teach the same concept; is able to identify primary differences in learners in the student population.	A. Demonstrates a command of alternative strategies to meet diverse needs and systematically provides activities that meet those needs.
B. Demonstrates the ability to effectively engage students in learning science, both individually and in group work of various kinds.	B. Regularly includes group as well as individual activities to teach science, allowing learners latitude in organizing groups according to their age and background.	B. Addresses the role of social and group interactions as a basis for conceptual learning and inquiry, and uses strategies to facilitate student abilities to form and organize their own groups.
C. Identifies goals and provides a well-reasoned rationale, based on student needs, for choosing particular science teaching strategies.	C. Shows flexibility in planning and applying teaching strategies, and uses ongoing observation and assessment to determine subsequent actions.	C. Readily articulates sound reasons for actions and is able to switch strategies quickly to take advantage of "teachable moments" and sudden insights.
D. Uses appropriate technology, including computers, to provide science instruction	D. Regularly incorporates available technology into instruction. Involves students in the use of technology for investigating, retrieving information and processing data; relates technology to the process of inquiry.	D. Identifies information technologies as fundamental to teaching, learning <i>and practice</i> of science and engages students both in use of technologies and understanding of their use in science and learning.

5.1.1 Preservice Level	5.1.2 Induction Level	5.1.3 Professional Level
E. Uses diverse teaching methods to address important concepts from different perspectives; and uses learning cycles for some instruction.	E. Builds a repertoire of teaching materials and learning cycles to address a concept from several perspectives.	E. Has a well developed set of thematically related materials and learning cycles used to teach concepts from different perspectives.
F. Identifies common student misconceptions or naive conceptions in the teaching field, their source, and an appropriate teaching response.	F. Begins to systematically identify and anticipate student misconceptions or naive conceptions and plans activities and discussions to address and modify them.	F. Regularly anticipates misconceptions and naive conceptions and uses assessment as the basis for constructing more scientifically acceptable concepts and relationships.

## 5.2 Rationale and Discussion

Science teachers and specialists should give all students opportunities to learn from instruction and make sense of science as a way of knowing. They should encourage students to want to do more science. This standard is grounded on assumptions that all students can learn science at some level (AAAS, 1989; NRC, 1996) and that teachers are creative decision-makers who do not just mechanically direct preset activities (Orlich et al., 1998; BSCS, 1995). Furthermore, teachers have a responsibility to continually change their practices to help students learn more effectively. Learning is a process of making sense of experiences rather than memorizing information. It requires integration of thoughts, feelings, and actions (Novak, 1984). Meaning is constructed by adding, deleting, and modifying information in an existing idiosyncratic conceptual framework (Spector, 1995; Novak, 1984).

Many factors shape a person's conceptual framework, including life experiences; social, emotional, and cognitive developmental stages (APA, 1992); inherent intelligences (Gardner, 1985); learning styles (Curry, 1990); race and gender (Lynn & Hyde, 1989); ethnicity and culture (Banks, 1993); and demographic setting (Orlich, et al., 1998). Teachers must be aware of the influence of these factors—real or potential—on student behaviors and abilities if they are to design effective learning opportunities.

In general, a learning opportunity targeting a particular concept should involve students in multiple interactions with events or objects representing various attributes of the concept. Novak (1984) defines a concept as a perceived regularity in objects or events, or records of objects or events, designated by a concept label. Understanding a concept is a matter of perceiving the regularity and relating it to other regularities.

Current thinking in education conceives of meaningful knowledge as a coherent network of concepts from which one can make cogent decisions, rather than a collection of relatively disconnected concepts and facts. To build these networks, teachers must provide learning opportunities requiring multiple interactions with appropriate objects or events. The more students encounter and make sense of objects or events that contain a regularity—the

concept—the more likely they are to incorporate the concept meaningfully into their world view. Multiple encounters give students opportunities to connect concepts and construct valid propositions and data-based theories (Spector, 1991). It follows, then, that an effective science teacher should have a repertoire of classroom, laboratory and field activities that are appropriate for the development of the major concepts of science by students at a given level.

Pedagogy, however, is not just concerned with development of conceptual knowledge. An important part of science education is to teach students the social processes of consensus building and engage them in the social construction of meaning (Zeidler, 1997). In other words science education, like education in all fields, should encourage students to think about thinking, facilitate creativity and critical judgement, and favor development of self-awareness (APA, 1992; Zeidler, Lederman & Taylor, 1992).

Methodologies for science teaching are abundant. Cooperative learning models, concept mapping, model building, role playing, games, simulations, analyzing case studies, questioning strategies, problem solving, inquiry strategies, field trips (on and off campus), research projects, electronic media presentations, reading, authentic assessment and reflective self evaluation are examples.

The use of computer games, simulations and processing programs may be particularly productive because they allow students to obtain, process, and transform data readily, and to compare multiple perspectives and interpretations of the data. By increasing the speed, ease, variety, and efficacy of learner engagements, teachers can make room for more for the hands-on/minds-on experiences so critical for engaging underrepresented and underserved students in the study of science (Gardner, Mason & Matyas, 1989; Kahle, 1983).

Experienced teachers must be able to exercise the professional judgement needed to match learning opportunities to a variety of existing conceptual frameworks and learning styles. They must provide learning opportunities which are flexible, diverse, challenging and accessible (APA, 1992) which, taken together, stimulate students' curiosity about the world around them. A teacher who offers diverse learning opportunities makes it more likely that each student will learn science at some level. Since sequencing of activities has been shown to be a factor in their effectiveness, teachers should be proficient in using available instructional models such as the learning cycle (Karpus, et al., 1977; BSCS, 1993; Bybee et al., 1989) or other demonstrably effective constructivist models.

Throughout their careers, effective teachers use student responses (Danielson, 1996) and new knowledge in the field to improve their practices. As professionals, science teachers should engage in continuous self-study, demonstrating improvements in their selection of strategies and methods over time, and justifying their professional choices by referring to research on learning, assessments of student outcomes, state and national goals for science education, and available resources.

The stages of concern (Fuller, 1969; Reeves & Kazelskis, 1985) of teachers must be considered in assessing their professional development. Most teachers begin their careers with a limited repertoire of knowledge and skills, and place high priority on day-to-day survival. Over time, with confidence, this self-centeredness usually yields to a greater concern for the needs and welfare of the students. In keeping with this, the teacher's ability to explain a given instructional decision should increase over time, demonstrating the ability to identify specific solutions to specific problems consistent with the interests and needs of the students.

### 5.3 Recommendations of the National Science Teachers Association

In most teacher education programs, skills of teaching are the responsibility of the education unit. While generic methods preparation for teachers across fields can lay the groundwork for further learning, NSTA regards specific preparation in science methods as essential for science teachers and specialists, and also elementary generalists.

In order to promote the pedagogy of inquiry, teacher preparation programs should maximize opportunities for active learning and inquiry in content science courses, consistent with the goal of the courses. Teachers who are comfortable with active, as opposed to passive, learning can be presumed to be more likely to use active learning in their own classrooms. Science teaching candidates should prove the ability to effectively use a variety of hands-on/ minds-on instructional activities appropriate for the discipline(s) and the level(s) they are preparing to teach, both in the classroom and in the field. They should be able to discuss the impact of sequencing on the effectiveness of instruction and use constructivist methodologies such as learning cycles to enhance student learning. The ability to effectively use appropriate and varied technology is essential.

Programs should give candidates ample opportunities to engage in instruction, both individually and as members of a teaching team. Prospective teachers should be provided with methods to assess the needs of classes and individual students, and should show an ability to choose from among a variety of activities and strategies to meet those needs. Candidates should exhibit dispositions allowing them to work effectively with students from a variety of racial, ethnic, religious and social backgrounds and should articulate rationales for their actions reflecting concern for responsible educational practice.

The best programs for science teacher preparation have a well defined set of indicators for effective pedagogy and provide students with multiple ways to display science teaching competencies in authentic settings. Work with K-12 students is a significant feature of the program. Indicators of pedagogy are consistent with best practices as defined in the science education literature and are each based on a solid, well-articulated rationale. Programs provide sufficient time, number and arrangement of experiences to ensure that candidates acquire the desired competencies. The best programs use a variety of contemporary assessment measures to measure performance in the most authentic and diverse settings available. They ensure that candidates work with students with varied abilities from different backgrounds and adjust their practices to meet different needs.

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## 6.0 Standards for Science Teacher Preparation: Curriculum

The program prepares candidates to develop and apply a coherent, focused science curriculum that is consistent with state and national standards for science education and appropriate for addressing the needs, abilities and interests of students. Science curriculum refers to:

- An extended framework of goals, plans, materials, and resources for instruction.
- The instructional context, both in and out of school, within which pedagogy is embedded.

### 6.1 Examples of Indicators

6.1.1 Preservice Level	6.2.2 Induction Level	6.2.3 Professional Level
A. Relates instructional goals, materials and actions to state and national science education standards, analyzing strengths and weaknesses in a particular classroom context.	A. Systematically develops a framework for instructional goals, materials and actions consistent with state and national science education standards.	A. Has a well-defined rationale for instructional goals, materials and actions in relation to state and national science education standards and student achievement.
B. Assembles a diverse set of potentially useful instructional materials in the teaching field from a variety of sources including the World Wide Web	B. Continuously searches for potentially useful instructional materials from commercial and professional sources, including meetings, journals, and colleagues.	B. Participates in the development of new and unique resources for colleagues in the school and in the science education community.
C. Develops and implements long-range and unit plans, with clear rationales, goals, methods, materials and assessments.	C. Interrelates concepts and experiences among units to create courses with thematic elements and well-defined goals in the teaching field.	C. Links experiences in the classroom to the broader world beyond; takes advantage of events and topics of interest; can redefine goals skillfully.
D. Understands the role of technology in education and can define a rationale and long-range strategy for including technology in science education.	D. Begins to plan and implement along-term strategy and plan for incorporating technology into science teaching.	D. Has a developed inventory of technology to use effectively to develop interest and excitement during inquiry and learning and uses technology to enhance student understanding of the relationship between science and technology.

6.1.1 Preservice Level	6.2.2 Induction Level	6.2.3 Professional Level
E. Designs and implements learning activities that thematically relate science with other school subjects and community resources.	E. Adapts learning activities to consistently and systematically connect science with other school subjects and community resources.	E. Creates a curriculum that integrates concepts, ideas and skills from many subject areas and the community, allowing students to take advantage of their strengths and interests in other fields to learn science.

## 6.2 Rationale and Discussion

The National Science Education Standards defines curriculum as "the way content is delivered . . . the structure, organization, balance, and presentation of the content in the classroom." (NRC, 1996, p. 2). The Third International Study of Mathematics and Science identifies three major dimensions: the *intended curriculum* (goals and plans), the *implemented curriculum* (practices, activities, and institutional arrangements) and the *attained curriculum* (what students actually achieve through their educational experiences) (Schmidt, et al., 1996a, p. 16). Well-prepared science teachers can plan, implement and evaluate a quality, standards-based science curriculum that includes long-term expectations, learning goals and objectives, plans, activities, materials, and assessments.

To be able to do this effectively, a teacher must be familiar with the professionally-developed national, state, and local standards for science education. State and local curriculum frameworks often provide the most specific guidelines for the structure and sequencing of content. Published instructional materials, such as textbooks, also may give teachers a scope and sequence for content, along with a model for practice and suggestions for instruction and assessments.

However, a good curriculum requires more than a textbook or curriculum guide. Published instructional materials are not always aligned with contemporary standards and frameworks. Many textbooks, for example, are concerned primarily with content, and contain more information than is practical for students to learn in the time available. They tend, along with U.S. mathematics textbooks, to be "a mile wide and an inch deep" (Schmidt, et al, 1996b, p. 62). U.S. science textbooks include many more topics than are typical in other countries and address the same topics for more years. As a result, no topic receives the kind of in-depth treatment that would allow students to develop meaningful and lasting understanding.

Textbooks cannot, as a practical matter, relate science to local concerns or recent events. Some may omit or de-emphasize key concepts, especially if they are controversial, or fail to differentiate more important from ancillary concepts. They may lack key curricular components (e.g., inquiry activities, assessment activities, educational technologies, connections with other subjects, suggestions for adaptations to special student needs). Texts by their nature also deliver the message that science is "stuff in books" and not the dynamic process of learning and inquiry that is at the heart of constructivism. Because of these limitations, the textbook, which is the past has served as a concise, *de facto* curriculum for many teachers, is being increasingly de-

emphasized in many of the best science classrooms.

In its place, many teachers, and schools, have chosen to work with colleagues, parents, and the community to construct a coherent, appropriate and relevant science curriculum based on contemporary standards and the assessed needs of students. The TIMSS report points out that "teachers serve as the final arbiters of curriculum intentions and they are the 'brokers' or 'midwives' of students' content-related learning experiences." (Schmidt, et al., 1996a, p. 18). Teachers plan, implement, and evaluate the curriculum for their classroom and may collaborate with administrators and peers to create the science curriculum for their school, district or state. To do so, they must review and adopt instructional materials, argue for their use, adapt materials to specific situations, adjust sequencing and duration of learning activities, assess student learning, and use various data to assess their practices. The traditional curriculum based on textbook readings and lecture assessed almost exclusively by written examinations, is no longer adequate for meeting science education goals.

The TIMSS has raised critical issues regarding science and mathematics education in the United States. The analysis of science achievement results for the middle years found that the United States falls below the median in comparison with other countries. Although the results were better for the primary grades, areas of science education in the United States clearly need strengthening. One explanation for the poor results from the United States is a lack of coherency and focus in the science education curriculum at the national level. The TIMSS authors write that "No single coherent vision of how to educate today's children dominates U.S. educational practice in either science or mathematics . . ." and "The visions that shape U.S. mathematics and science education are splintered" (Schmidt et al., 1996b, p. 1). The curriculum in the country with the best science achievement is presented in a way that links topics and concepts into a story. The need for more coherence is one reason that the National Science Education Standards (NRC, 1995) includes thematic strands.

Another change that has gained momentum over the last decade is the integration of science, mathematics and technology (Hamm, 1992). Ault (1993) has suggested a number of ways to integrate science with technology ranging from instructional technology to design and engineering. The desire to include technology is a reflection of perceptions that science is too often taught as an end to itself, rather than as a means to an end. In that vein, criticism has been directed toward colleges and universities for "decontextualizing" science, i.e., removing it from any specific context (Hull, 1993). The loss of context makes it difficult for students to understand why a particular concept is important or how it relates to their personal world.

Gilbert (1997) proposed a framework for sequencing science in a way that is consistent with the developmental needs of students, focusing on the development of personal science in the lower grades and progressing to diversified, contextualized science in high school. Since most university science courses are taught in a decontextualized format, infusion of workplace experiences and applications must generally be intentional, through supplemental instruction, internships or applied course work. Contextualization does not appear to be a major concern of science teacher preparation programs at present, but recent concern in many states with "school-to-work" transitions may have important ramifications for science teaching and teacher preparation.

### 6.3 Recommendations of the National Science Teachers Association

Science teacher candidates at all levels should be able design and implement curricula that are consistent with professionally developed state and national standards and the National Science Education Standards. Not only should these standards be familiar to science and education faculty, but the overall teacher preparation curriculum should be designed to ensure that new teachers have the conceptual knowledge, skills and understanding needed to implement them.

Prospective teachers should be able to evaluate curricula and curriculum materials against appropriate standards and make judgements about whether to accept, modify or reject such materials based on the results. They must be able to collect, organize and use materials from a variety of sources, including community resources, in the curriculum. They should have strong planning skills enabling them to arrange and align appropriate goals, methods and assessments in their plans.

Because research shows a strong link between the perceived relevance of a subject and achievement in that subject, students should be familiar with applications of science in the community and science-related fields, such as nursing, agriculture, engineering. Programs should collaborate with persons or institutions in the community to develop opportunities for students to understand their science(s) in the workplace and everyday life.

Students must have the opportunity to demonstrate competency in designing long-term plans for instruction that achieves state and national goals and relating science to the instructional context of the school and community. These plans should reflect the importance of technology in science instruction and identify points at which technology is appropriately integrated into the curriculum.

The best teacher preparation programs provide opportunities for its students to engage in science and science-related learning experiences in contexts extending beyond the classroom. Candidates can develop thematic curriculum materials integrated with other school subjects and community resources. Prospective teachers in these programs are familiar with state and national professional standards and can develop appropriate short- and long-range instructional plans based on these standards. They can find and evaluate the suitability of a range of teaching materials from many sources, including the World Wide Web. They are technologically literate and can adopt and adapt methods, materials and technology to achieve the goals of instruction.

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## 7.0 Standards for Science Teacher Preparation: Social Context

The program prepares candidates to relate science to the community and to use human and institutional resources in the community to advance the education of their students in science.

The social context of science teaching refers to:

- Social and community support network within which occur science teaching and learning.
- Relationship of science teaching and learning to the needs and values of the community.
- Involvement of people and institutions from the community in the teaching of science.

### 7.1 Examples of Indicators

7.1.1 Preservice Level	7.1.2 Induction Level	7.1.3 Professional Level
A. Identifies people and institutions in the community who are willing to assist in teaching certain topics, and plans for their involvement in teaching.	A. Involves members and institutions of the community with appropriate expertise or relevance in science instruction.	A. Develops a network of community members and institutions to call upon to help in science instruction.
B. Uses data about a community, its culture and its resources to plan science lessons that are appropriate for, and relevant to, students from that community.	B. Collects data about the community, its resources, and the students and experiments with ways to use that data to plan science lessons that are most appropriate for those students.	B. Regularly uses information about the community, its resources, and the students to plan relevant and appropriate science instruction.
C. Plans activities that involve families in the science teaching/learning process and communicates effectively with families of students.	C. Selects or designs activities to involve family members in the teaching and learning of science, and communicates systematically and effectively with parents or guardians.	C. Designs and employs a range of activities to cultivate a relationship with families in support of science instruction.

### 7.2 Rationale and Discussion

Educational resources are of two kinds: those that facilitating teaching and those helping students prepare to learn (Danielson, 1996). It is the teacher's responsibility to identify resources and use them effectively to help students learn. The full potential of each student can only be tapped if science teachers are aware of people, items, and services available both in and out of school.

Several researchers (Ford, 1993; Nieto, 1992; Patthey-Chavez, 1993; Rivera & Poplin,

1995) have found that teachers often do not know much about the families and communities of some of their students. Many teachers in urban communities do not reside in the same neighborhoods as their students. Therefore, they are not familiar with community resources available to help them teach science effectively. Resources can include transportation and health care facilities, businesses, family members and individuals in the community (NRC, 1996).

According to the National Science Education Standards (NRC, 1996), teachers of science should be able to "identify and use resources outside the school" (p.3). Families are perhaps the most important of these resources. Communication with families of students should go beyond informing them of events in class (in the families' native language). It should give them an opportunity to be involved in the science curriculum. Interested parents, guardians, and community members may participate in identifying and selecting goals, designing curriculum and delivering instruction.

With small effort, teachers may often find parents, guardians and community members with unique and appropriate knowledge and skills related to science. Parents may share stories about the use of herbal medicines and may be a source of legends and myths related to natural phenomena. They may conduct students on tours of businesses that apply science and technology, such as dry cleaning establishments, hair salons, pharmacies, food processing operations, farm, cattle and dairy operations, construction, automotive shops, engineering labs, and health labs.

Other, more traditional, opportunities to investigate the community are also important. Field trips to rivers, sewage treatment plants, water filtration plants. Visits to various industries may help students understand how humans use natural phenomena to their advantage, and also to understand the costs of these benefits. Tours of businesses and industries help students connect school science and the workplace. Experts in assorted fields including engineers, coroners, medical technicians, physicians, wildlife experts, ballistics experts, and veterinarians are resources often available in the community.

Teachers need to be aware of the cultural identities of their students. Culturally relevant teaching (Atwater, Crockett & Kilpatrick, 1996; Larson-Billing, 1995) helps science come alive for many students, especially those who have traditionally been uninvolved in science. Examples, analogies, and investigations based on students' personal experiences and on cultural contexts promote curiosity and help students build a personally meaningful framework in science (Atwater, 1994). Involvement of families and the community in the teaching of science will facilitate the development of links to the community's cultures.

Most families and communities ostensibly value science education, but may display these values in different ways. Sometimes values—often religious values—may directly conflict with tenets of science. Teachers should study the composition of the community carefully and become fully aware of such conflicts. Teachers of science should not feel forced to compromise the values and ethics of what they teach. Instead, they must find ways, through study and analysis, to accommodate these deeply held beliefs—for example, by discussing beliefs at a different level, i.e., by examining the role of belief in all human thought knowledge. By understanding that students are a product of the community, teachers may often find better ways to ensure that science is meaningful to them.

### **7.3 Recommendations of the National Science Teachers Association**

This standard is intended to facilitate inclusion of members of the immediate community and the family in the teaching of science. While much of the preparation related to this standard is the responsibility of the education faculty, science faculty can also contribute by identifying and using community resources in their classes. Guest speakers and field trips can broaden the horizons of science students at any educational level.

Because of the increasing diversity of the communities and schools in America, teachers must develop a vision of education that looks beyond the confines of the classroom walls, and beyond themselves as sole arbiters of knowledge. Prospective teachers of science should be required to study the science-related resources in their community and to include appropriate community resources in their practice teaching. They should be taught how to find resource leads, follow up on them, and integrate them into their teaching.

Candidates should also be provided with opportunities to study a community and use accepted methods to determine the cultural differences that exist. They should then be able to identify ways to integrate this knowledge into the science curriculum to make it more relevant to the students.

While in student teaching, students should provide evidence of contact with families of one or more students. Where appropriate, they should include activities and projects that involve family members in teaching or researching matters related to science. They should include activities in their curriculum designed deliberately to involve the family and communicate with them.

Colleges and Universities in culturally homogenous areas—regardless of the cultural or ethnic composition of the area—should find ways to involve prospective teachers in experiences that will familiarize them with other cultural values. Perhaps most important is the ability to analyze cultures based on an understanding that the candidates themselves are viewing the results with a cultural bias.

Colleges and universities should try to recruit and retain people from groups underrepresented in the sciences. Programs might consider conducting activities such as future science teacher clubs, "Science Teacher for Tomorrow" courses, urban intern programs, and "Diversity Retreat, Day of the Science Teacher, and Award Ceremony." These activities contribute to the experiences of preK-12 teachers and community members alike.

The best programs for science teacher preparation have requirements that involve prospective teachers in the community early and provide methods and opportunities for the teachers to become familiar with available resources. They require demonstrated interaction with families and community resources to involve them in science teaching during field experiences and may require service learning in some courses. Such programs require evidence that candidates understand the cultures of their students and use examples and references from different cultures to involve these students. In geographical areas where cultures are homogenous, the program includes specific opportunities for students to study cultural diversity and address such differences through videotapes and case studies, for example.

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## 8.0 Standards for Science Teacher Preparation: Assessment

The program prepares candidates to use a variety of contemporary assessment strategies to evaluate the intellectual, social, and personal development of the learner in all aspects of science.

Assessment refers to:

- Alignment of goals, instruction and outcomes.
- Measurement and evaluation of student learning in a variety of dimensions.
- Use of outcome data to guide and change instruction.

### 8.1 Examples of Indicators

8.1.1 Preservice Level	8.1.2 Induction Level	8.1.3 Professional Level
A. Identifies and uses the most appropriate methods for gathering information about student learning, based on student needs and characteristics and the goals of instruction.	A. Employs multiple methods to systematically gather data about student needs, abilities and understanding and reflects upon goals of instruction.	A. Creates new methods for helping students demonstrate knowledge, and uses results to alter classroom practices.
B. Aligns assessment with goals and actions and uses results to alter teaching.	B. Guides students in formative self-assessment, relating each tool to a specific learning outcome.	B. Regularly and consistently provides students with varied opportunities to demonstrate their individual learning.
C. Demonstrates the ability to use multiple strategies to assess teaching and learning authentically, consistent with national standards and goals for science education.	C. Uses multiple resources for assessment and can cite changes in practices made because of assessment.	C. Continuously experiments with new assessment techniques, including those suggested in the literature, and reflects on its meaning for altered practice.
D. Engages in reflective self assessment and develops a system for self-assessment as a practicing teacher.	D. Engages in reflective self assessment and uses a system to self assessment, modifying practice and the system of assessment as required.	D. Regularly modifies and informs practice through multiple self-assessment indicators.

### 8.2 Rationale and Discussion

Many efforts are currently underway to develop methods to authentically assess the knowledge and skills of students. Paper and pencil testing has been and continues to be the dominant mode of assessing the outcomes of formal education, and acquisition of content is often the dominant goal. However, most educators acknowledge that written tests assess only a very

limited range of student abilities and may restrict the ability of capable students to express themselves in other mediums. Critics have noted that grades, in and of themselves, provide no evidence of what has been taught, what has been gained, or how well it has been measured.

The National Science Education Standards (NRC, 1995) give the topic of assessment considerable attention, an emphasis that highlights the importance of assessment to science teachers, who are called upon to evaluate diverse skills. Contemporary teachers must feel confident in using authentic assessment to measure achievement of science standards and benchmarks (Project 2061, 1997).

Assessment is not a punitive action. Its purpose is not to catch and punish students who have not learned. Instead, assessment is a process of learning by both the teacher and the student. Good assessment strategies help students learn about their strengths and weaknesses, building upon the former and remedying the latter. Assessment has failed when it results only in a sense of failure or incompetence for sincere students. A wise observer once remarked that many students leave school with more of a sense of what they cannot do than what they can. Reflective teachers help their students identify and celebrate their achievements. As Webb (1997) notes, we must measure what we claim to value as student skills, including the ability to contribute productively as members of a society.

Central to the process of authentic assessment is the concept of alignment. Alignment refers to consistency between goals, actions and assessments. Is instruction likely to lead to attainment of the identified goals? If so, is the chosen manner of assessment valid? Does it really measure what it purports to measure? Assessment may be invalid when it (a) does not address the content in the assessment; (b) does not align the assessment with the goal—even if it aligns with instruction, or (c) does not align assessment with the way instruction takes place e.g., a multiple choice test used to assess learning that has taken place using higher level analysis and reasoning skills. Problems with alignment are common. New teachers must learn how to design instruction and assessments that are consistent with multiple goals, not just those aimed at content acquisition.

In a climate of positive assessment, learners and their teachers look for evidence to document growth and for new ways to show what students can do. Diagnostic, formative and summative assessment strategies are woven throughout instruction as a natural part of the classroom activities. Portfolios are often used to collect evidence of growth and change. Multiple assessment methods including videotapes, demonstrations, practicum observations, discussions, reports, simulations, exhibitions and many other outcomes are useful alternatives to the traditional written test. Peer assessment in cooperative learning groups is especially useful for demonstrating skills using laboratory equipment, and for evaluating process skills such as the creation and interpretation of graphs. Computer-based testing can help students diagnose their own abilities while placing fewer demands on teacher time.

Authentic assessment has become an important part of educational reform. It is ". . . assessment that mirrors and measures students' performances in 'real-life' tasks and situations" (Hart, 1995, p, 106). Beginning teachers of science show competence developing and using both authentic and traditional, assessment strategies. Darling-Hammond, Ancess and Falk (1995) describe five schools in which curriculum-embedded assessment is part of the regular instructional program. Through the use student projects with final summary reports, portfolios with rubrics for identifying standards of student performance, evaluations by outside experts, and a steady flow of

feedback to learners, each of these schools provides students and parents with information marking progress toward learning goals. Roth (1995) provides additional descriptions of authentic school science and its practice.

Involving students in designing the rubrics that will be used to assess their work is often effective. Anderson and Page (1996) provide examples of how this can be done. The preparation of teachers should include opportunities for them to take part in designing and defending rubrics for their own reflective self-assessment. Reflective teachers continually seek evidence for their own success in helping their students achieve learning objectives. They may use audio and video recordings to examine their performance and often invite peers, and supervisors to observe them and make suggestions for improving their practices. They frequently construct professional portfolios with artifacts and reflective commentary, recording their perceptions of their success and failure as a teacher. Reflective teachers encourage constructive evaluations of instruction by their students.

Professional teachers accept responsibility for judging the relative success of activities they design (NBPTS, 1996). They monitor the successes and failures of both individuals and classes. Such teachers use information about how students are doing "on average" to analyze the success of their instructional strategies. They know how to align instructional practices and materials with outcomes as measured on carefully selected assessment instruments (Webb, 1997).

### **8.3 Recommendations of the National Science Teachers Association**

The need for assessments that measure more than one dimension of learning are as necessary at the college and university level as they at precollege levels. Institutions should expand the range of assessments used in university courses, encouraging university instructors to adopt goals beyond the mere transmission of information. Science and education courses in the teacher education program should model the authentic assessments recommended by national standards projects, including the National Science Education Standards. Preservice candidates should be assessed using multiple indicators, and these assessments should be used, in part, to assess the science teacher education program itself.

Teacher education programs should engage students in regular self-assessment and should help them develop a workable self-assessment system for use during student teaching and the first years of practice. They should introduce prospective science teachers to a broad array of assessment techniques and develop standards for good practice against which they can assess their work.

NSTA recommends the development of a culture that does not perceive assessment as an endpoint in a linear program of instruction, but perceives it as a constant process of learning for self-improvement. Quality education is based upon the premise that assessment should take place at many points in the educational process, instead of at the end of the process.

The best teacher education programs engage students in learning and use of a broad range of assessments aligned with the goals and experiences they provide. They use the extensive assessment standards from the National Science Education Standards (NRC, 1995) as a baseline for development. Such programs model good assessment throughout their programs and develop and employ systems to ensure the competency of their graduates. They prepare prospective teachers not only to assess and evaluate their students, but to engage as well in regular self-

assessment and use the results to guide their practices.

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## 9.0 Standards for Science Teacher Preparation: Environment for Learning

The program prepares candidates to design and manage safe and supportive learning environments reflecting high expectations for the success of all students. Learning environments refers to:

- Physical spaces within which learning of science occurs.
- Psychological and social environment of the student engaged in learning science.
- Treatment and ethical use of living organisms.
- Safety in all areas related to science instruction.

### 9.1 Examples of Indicators

9.1.1 Preservice Level	9.1.2 Induction Level	9.1.3 Professional Level
A. Identifies and promotes the elements of an exciting and stimulating science learning environment; plans and develops opportunities for students to learn from resources, events and displays in the environment.	A. Creates a classroom that reflects a commitment to science inquiry and learning, and gives students the opportunity to learn on their own.	A. Provides many opportunities for students to engage in inquiry in a variety of ways, through learning centers, exhibits, printed materials, displays, posters, aquariums, terrariums, etc.
B. Understands and sets up procedures for safe handling, labeling and storage of chemicals, electrical equipment, and knows actions to take to prevent or report an emergency.	B. Exercises safe practices in classroom and storage areas, and demonstrates that safety is a priority in science and other activities; can take appropriate action in an emergency.	B. Systematically ensures safety in all areas and takes whatever steps are necessary to ensure that the school science program is conducted safely.
C. Understands liability and negligence, especially as applied to science teaching and can take action to prevent potential problems.	C. Takes action to prevent hazards and communicates needs and potential problems to administrators	C. Stays informed of potential hazards and legal concerns and communicates with other teachers to maintain a school environment free of potential problems.

9.1.1 Preservice Level	9.1.2 Induction Level	9.1.3 Professional Level
D. Knows the standards and recommendations of the science education community for the safe and ethical use and care of animals for science instruction.	D. Adheres to the standards of the science education community for ethical care and use of animals; uses preserved or live animals appropriately in keeping with the age of students and the need for such materials.	D. Adheres to the standards of the science education community for ethical care and use of animals; uses preserved or live animals appropriately in keeping with the age of students and the need for such materials.

## 9.2 Rationale and Discussion

The National Standards for Science Education (NRC, 1995) identify the dimensions of the learning environment as (a) time for extended investigations; (b) a flexible and supportive setting for inquiry; (c) a safe working environment; (d) sufficient resources, including tools, materials, media and technological resources; (e) resources outside school; and (f) engagement of students. Some of these factors have been dealt with in other standards and will not be repeated here.

Sustained, high quality education is the product of high quality teachers, but it is also important that teachers have the resources to do the job properly. Schools and school districts recognized for quality generally have strong, active community support with regard to resources. Teachers of science should provide a learning environment that (a) provides for the physical needs and variations of learners, including disabled learners; (b) provides for the safety of all students; (c) is orderly and well managed; (d) is physically and socially appropriate for the age and maturity of the learner; (e) stimulates interest and engagement in learning and (f) recognizes and respects the need for appropriate and humane treatment of living things.

Weld (1990) discusses the need to provide an accessible environment for all science students, including those with special needs. Teachers must demonstrate awareness of the impact of special needs on potentially difficult activities such as field trips. They should also be aware of steps they can potentially take to meet the needs of all learners, from customizing equipment to adapting lessons to using cooperative learning approaches.

Teachers should be aware of issues related to the keeping of animals in the classroom. The U.S. Humane Society, recommends stringent controls on the keeping and handling of animals in the classroom (Carin, 1997). The National Association of Biology Teachers does not recommend such restrictions, but does recommend careful attention to the humane care and use of animals, awareness of dangers, and the use of alternatives to dissection when they are available (NABT, 1990). Plants may also be hazardous, both in and outside of the classroom (Riechard, 1993).

Safety and liability are of particular concern to science teachers, given the variety of environments they may teach in and materials they may use. Nagel (1982) recommended that safety education should be a condition of certification. Flinn Scientific Inc. (1992) has developed a generic chemical hygiene plan for high school laboratories covering many procedural issues. Guidelines and recommendations are also available from the American Chemical Society for chemistry laboratories (ACS, 1995). Yohe and Dunkleberger (1992) have suggested an inservice

format for teaching safety that is applicable to all teachers of science.

In the same vein, teachers should also be aware of the legal issues related to liability for their actions. Purvis, Leonard and Boulter (1982) have delineated the conditions of negligence and liability and related them to school science in the important areas of lab security, appropriate facilities, proper instruction and protective gear. Because science teachers are particularly likely to encounter injuries among their students, they should thoroughly understand the criteria for liability for negligence and defenses against negligence. By being aware of their responsibilities, they can act to ensure the well-being of the students under their care.

### **9.3 Recommendations of the National Science Teachers Association**

The importance of a supportive facilitative environment for learning cannot be overemphasized. Students in a science teacher education program should know how to develop and maintain an atmosphere conducive to the learning of science through investigation and inquiry. This includes the establishment of a stimulating physical environment that raises curiosity and establishes a sense of security and community. In addition, the environment should communicate ideas and concepts, and increase motivation to learn through displays, exhibits, and artifacts.

Teacher preparation programs must give candidates the knowledge needed to maintain a safe environment for students by avoiding or controlling chemicals, plants and animals that may be hazardous to students; storing, cleaning up spills and disposing of chemicals safely; give safety instructions and use safety equipment properly; avoiding hazards of improperly shielded electrical equipment; properly instructing on field trips, and teaching students to avoid fire hazards and biological contaminants. The need for such preparation varies with the grade level and discipline for which the teacher is earning licensure. Most program today do little with safety, other than routine safety instruction provided with courses. The dangers in science are greater than in most other fields and the threat of liability should persuade teacher education programs to pay more attention to this issue.

Teachers of science should be knowledgeable in the safe and ethical care of animals in the classroom. They should be sensitive to student attitudes and should treat living things with respect. Furthermore, teachers should know and comply with professional standards for classroom treatment of animals and should be aware of laws and regulations controlling the use of sentient, usually vertebrate, animals. The routine use of animals in university lab classes seldom teaches prospective teachers respect for animals, and does almost nothing for their knowledge of care for animals. All programs preparing teachers likely to keep animals in their classrooms – biology, general science, elementary and middle-level science – should address animal care.

Technology is a part of the classroom environment. Teachers of science should incorporate computers, multimedia, and other technology into instruction to the greatest extent possible. Technology can enrich an environment and enhance learning. With it, students can participate in experiences and projects that would otherwise be impossible. They can communicate with other students around the world. Its presence creates a link between technology and science and extends the learning environment well beyond the classroom walls.

The best teacher preparation programs ensure that candidates can create and maintain an effective classroom environment, establish routines, and enrich the environment for all students.

Prospective teachers from such programs express understanding and appreciation for the role of environment and context in promoting understanding and learning of science and can identify ways to enhance the environment. Such programs prepare students to demonstrate competency in maintaining a safe environment and enforcing rules necessary to safeguard children, animals and property under their care. They give significant and substantial attention to safety requirements and require students to pass a performance-based test on safety before releasing them into classrooms. They expect teachers who are likely to work with animals to have a good understanding of NABT and state guidelines for use of animals.

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## 10.0 Standards for Science Teacher Preparation: Professional Practice

The program prepares candidates to participate in the professional community, improving practice through their personal actions, education and development. Professional practice refers to:

- Knowledge of, and participation in, the activities of the professional community.
- Ethical behavior consistent with the best interests of students and the community.
- Reflection on professional practices and continuous efforts to ensure the highest quality of science instruction.
- Willingness to work with students and new colleagues as they enter the profession.

### 10.1 Examples of Indicators

10.1.1 Preservice Level	10.1.2 Induction Level	10.1.3 Professional Level
A. Develops and states personal goals and a philosophy of teaching based on research and contemporary values of the science education community.	A. Regularly reflects upon his or her philosophy and goals and their relationship to actual teaching practices and adjusts practice as needed to bring them into alignment.	A. Has a well-developed philosophy consistent with the latest educational research, and effective practices in science education.
B. Understands the concept of a community of learners and interacts with instructors and peers as a member of such a community.	B. Applies the concept of a community of learners to science teaching and learning in the school environment.	B. Works with others science professionals to develop opportunities for continuous learning as members of a professional education community.
C. Documents personal strengths and weaknesses and seeks opportunities to improve his or her preparation to teach science.	C. Pursues and documents formal and informal learning opportunities, to strengthen his or her ability to teach science.	C. Shows a record of professional growth and development and demonstrates an ongoing commitment to improving science teaching practice.
D. Takes personal responsibility for growth and for assisting others who are preparing to teach science.	D. Takes responsibility for assigned classes and students and works with other teachers to develop high quality learning experiences in science.	D. Takes responsibility for new science teachers, student teachers and practicum students and works with them collegially to facilitate their growth and entry into the profession.

10.1.1 Preservice Level	10.1.2 Induction Level	10.1.3 Professional Level
E. Demonstrates the ability to handle problems and tension calmly and effectively, and to relate to peers, instructors and supervisors with integrity.	E. Treats colleagues, students and supervisors with respect and takes action to solve problems amenable to solution.	E. Demonstrates a record of professional integrity and the respect of colleagues, administrators and students.
F. Participates in student associations, workshops and activities related to science teaching and reads journals of professional associations in the field.	F. Joins state and national professional associations for science teachers and regularly reads publications to improve teaching and stay abreast of current events in the field.	F. Attends regional, state and some national conventions, conferences and workshops in science education; takes leadership or participates as a presenter in such gatherings.

## 10.2 Rationale and Discussion

Teaching becomes a profession when teachers practice with a common knowledge base and apply their knowledge to effective practice (Wise & Leibbrand, 1993). Professional practice, based on an accepted knowledge base and state of the art pedagogy, lies at the heart of educational reform. Professional teachers must "... be capable of profound reflection on practice, competent to enter into dialogue of the practice they know and the theory or literature they read; able to engage in ... interpretation and critique with colleagues and with children; and able to observe, document, and analyze their own practice and experience, and take that analysis into the white-hot cauldron of public forums and public accountability" (Socketed, 1996, p.26). To achieve the status of a true profession, we must move forward common vision that identifies quality practices and ensures that unprepared candidates and teachers are either counseled out of teaching or provided with remediation.

The contemporary literature provides numerous insights into the major components of professional practice that go beyond the stereotypic notions of professional practice based only on objective notions of skills, expertise, and knowledge. Avis (1994) asserts that professional practice, as it is traditionally defined, "fails to address the critique voiced against professionalism in the '60s and '70s and in particular those that focused on the generation of class and gender inequalities in the school system ... It is only by moving beyond the limitations of traditional professionalism that we can hope to develop an education that is potentially transformative and that engages seriously with the issues of society" (p. 66).

Society increasingly expects more than skilled technical labor from recognized professionals. Sergiovanni (1992) points out that these competencies must be linked to a set of professional virtues. Truly professional teachers must be committed to practicing in an exemplary way, moving toward valued social ends and an ethic of caring—toward meeting the needs of the professional community rather than just one's own needs.

Commitment to exemplary practice means staying abreast of the latest research in practice, examining one's own teaching, experimenting with new approaches, and sharing insights—in other words, becoming a reflective practitioner. Roychoudhury, Roth & Ebbing (1993) state that the

process of becoming a reflective practitioner is facilitated by numerous opportunities to develop the skills of reflection in the context of real life experiences. By working with multiple variables and their interactions, teachers develop increasing skills in decision-making. The ultimate goal of professional practice is for teachers to move toward empowerment and accept responsibility for their own professional growth.

The teacher's commitment to valued social ends stems from the recognition that there is an important relationship between teaching and the greater social good. Professionalism, at least in teaching, is founded on an ideal of service. Labaree (1994) stresses the need for schools and teachers to prepare students to function independently as citizens in a democratic society by expanding their critical thinking and problem-solving skills. Achieving this goal offers education transformative power by engaging students in the study of issues now facing society.

The ethic of caring requires a shift away from mechanistic, generalized and impersonal professional techniques based on a sterile philosophy of objectivity. Too often, Sergiovanni (1992) points out, administrators and teachers view unique students as cases to treat rather than individuals to serve. More attention is given now than in the past to understanding student differences and developing strategies to address a diversity of learning styles. Because positive relationships generally lead to more positive outcomes, professional teachers must build a caring environment in which learning can take place.

A commitment to practice beyond the level of one's own needs is fundamental to professional development. At the heart of this commitment is a willingness to acknowledge the need for trust and collegiality, and the value of sharing through a community of learners. As a school develops into a community of learners, the practice of teaching becomes less individual and more collaborative. At its best, the concept of collegiality is a state of common commitment to learning that encompasses teachers, students, administrators, and the professional community. It does occur automatically through shared work assignments, but instead appears to develop from shared purpose. A key element is trust. Mann (1995) found that teachers can be their own best resource for improvement when their ideas are trusted and supported. He describes a program in which the school culture values and supports so-called soft interventions – change from within – thus creating a school climate expecting and celebrating professional practice.

However, professional practice may result in internal conflict. Dipaola & Hoy (1994) found that conflict was greatest in schools with more professionally oriented teachers and concluded that professionalization was a militant process. Sence (1990) refers to a state of "creative tension" in professionalized climates: True professionals have learned the art of disagreeing without being disagreeable and realize that professional growth requires taking risks.

Intrinsic motivation is imperative if teachers are to move toward collaborative practice. Lortie (1975) describes extrinsic rewards as factors that are independent of the employee who fills the position, such as salary, prestige, and power. Intrinsic rewards, on the other hand, are determined by the individual, based on personal values and beliefs. The literature is replete with studies affirming the central role played by intrinsic motivation in facilitating professional development (Bookhart and Freeman, 1992; Green & Weaver, 1992; Espinet, Simmons & Atwater, 1992; Serow, 1994; Rogers, Bond, & Nottingham, 1997).

These components of professional practice, and the supporting research base behind them, challenge us to form a vision and create a path toward personal professional growth. The traditional model in which individuals are left alone to teach is rapidly being supplanted by a more

comprehensive model emphasizing the development of communities of learners. The commitment of teachers to the goal of improvement is fundamental to the success of efforts to professionalize.

### **10.3 Recommendations of the National Science Teachers Association**

Professional practice generally denotes a commitment to a set of governing principles that are in the best interests both of the profession and the clients they serve. At the top of the list in most professions is a commitment to the quality standards agreed upon by the community of practitioners.

Prospective teachers should be strongly encouraged, early in the program, to engage in professional activities beyond classroom work, such as seminars and workshops, professional conferences and conventions of local, state and national science teachers associations. Students who accept leadership roles should be given appropriate credit and recognition. Students should formulate a definition of professionalism and use that definition to build in their portfolios a record of professional accomplishments.

Teacher candidates should always exhibit dedication to the highest ideals of honesty, integrity and service. They should understand and acknowledge their role as an individual in a collaborative endeavor, and should recognize the need for positive interactions with others in the system, including administrators, colleagues, faculty, staff, parents, and students. They should always treat students with respect, even when addressing disciplinary problems that might arise. They should support the profession and seek to address problems within the system first.

The best programs in teacher preparation have written standards for professional behavior and clearly expect new teachers to develop a record professional development beyond the program. They provide regular opportunities for engagement in activities or associations in science education and encourage and recognize leadership in many areas. They develop a community of learners in science dedicated to quality enhancement, encouraging cooperation, collaboration and mutual enhancement. These programs actively promote professional behavior and take steps to encourage a professional orientation whenever possible.

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