Knowledge Base Supporting the 2011 Standards for Science Teacher Preparation

NSTA Standard 1: Content Knowledge

Over the last ten years, federal mandates such as No Child Left Behind (NCLB) Act of 2001 have required increasing levels of accountability to position highly qualified teachers in each classroom; teachers who possess the content knowledge and skills to deliver instruction to all students. Although some flexibility in this law has occurred over time, the expectations for placing disciplined trained teachers who are strong in content remains. Similar to NCLB, the Secretary of Education's 2002 report using empirical data found that verbal ability and content knowledge are the more important attributes of highly qualified teachers. Yet it is clear that multiple attributes including, content knowledge, are critical to promoting positive student learning outcomes.

A major report of the National Research Council (1999) establishes that for science teachers to be effective, they must "a) have a deep foundation of factual knowledge, b) understand facts and ideas in the context of the conceptual framework, and c) organize knowledge in ways that facilitate retrieval and application (p. 16). While transcripts document that a variety of courses have been taken, it has become common practice for state-wide or nationally used tests of content knowledge to be required for licensure. Since the nineteenth century, teachers have been subjected to tests of the content that the teacher was to teach (Ravitch, 2002). Such tests were one-time events and have, over time, become a commonplace requirement for licensure in most states in the union. Although the use of tests in licensure is seen as an indicator of the quality and of the breadth of content knowledge, such tests are "mastery tests" that measure only a minimum score required and they may also be culturally biased. Further, there is no conclusive evidence that the test accurately measures the kind of content knowledge that a teacher needs, and tests, therefore, cannot assure a difference in teacher quality (Angrist and Guryan, 2008). However, the reality of the licensure process is that virtually every state verifies the breadth of content knowledge by at least one test, and this testing is one of the most common requirements in licensure regulations across this country. This makes factual knowledge and conceptual understanding of critical importance for every program preparing future science teachers.

The degree to which the breadth and depth of content knowledge is responsible for excellence in the classroom is an unanswered question. Some research shows that content knowledge to a depth necessary to see it from many perspectives may be the single most important factor in the preparation of teachers (Hill and Ball, 2009). Yet other research suggests that content knowledge is frequently shown in the research to be one primary characteristic of the competent teacher who also needs to know how to teach the material they know (Darling-Hammond, 2006; Grossman, Schoenfield and Lee, 2005; Kellough, 2003; Diaz, et.al., 2006). Some efforts in the improvement of science teaching represent that knowing content both broadly and at a deep level is a prerequisite to good teaching (Project 2061, 1990; National Research Council, 1996; Bybee, 2010). The importance of content knowledge continues today.

The somewhat controversial report *Educating School Teachers* (Levine, 2006) argues that five-year teacher preparation should be the norm featuring a broad liberal arts preparation and a major in the area the student intends to teach. The National Academies' COSEPUP report proposed incentives for programs to result in bachelor's degree in science or engineering with teacher certification earned concurrently (2005).

Some research, although limited in scope, (Magnusson, Borko, Krajcik, J. S., and Layman (1992) has noted that teachers who have strong content training generally have higher student test scores and possess fewer misconceptions about science concepts compared to noncontent trained teachers. Additionally, Heller et al. (2003) research revealed that teachers with more content knowledge are more likely to use best practices that fully support student's content construction and development of abstract concepts in science.

NSTA Standard 2: Content Pedagogy

Students come to class with sophisticated ways of thinking about the natural world based on their interaction with the environment. They also learn by communicating with others, playing outside, and interacting with multimedia. Scientific knowledge develops over time with sustained opportunities to work with and develop ideas through scientific practices; such as establishing, extending, refining, and revising theories by collecting, analyzing, and interpreting data. All domains of science share common practices that are based upon a commitment to evidence and data as the foundation for developing claims through problem solving and inquiry approaches.

Students come to class ready to learn having interacted and experienced the natural world multiple times and in different contexts. Science is a natural extension of students' desire to learn about their world. Students have sophisticated ways of thinking and interpreting the natural world based upon direct experiences with the environment (Bruner, 1961). Scientific ideas and understandings are developed by communicating with others, playing outside, and interacting with multimedia. Students have sophisticated reasoning abilities that can be used as a basis for teachers' instruction. Due to the manner in which students have developed their scientific knowledge, teachers should base their instruction and lesson plans on the ideas and experiences of the students. The understanding of concepts develops over time by relating the concepts to one another, prior knowledge, and experience, rather than learning topics as unrelated bits of knowledge.

Research strongly suggests that a more effective approach to teaching and learning science is to use students' prior knowledge and experiences, and allow the students to support or revise their theories by collecting, analyzing, and interpreting data, and asking questions (Polman and Pea, 2001). Teaching students how science is accomplished is an important goal of science education (National Research Council [NRC], 2000; American Association for the Advancement of Science, 1993). The process of doing science includes all of those practices in which scientists solve problems. Inquiry is one such process or practice and has been defined as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (NRC, 1996, p. 23). Some research has suggested that the level of students' prior knowledge with doing science through inquiry should be taken into account when developing lesson plans and instructional activities (Krajcik, 1998). Students should be able to use scientific practices in order to understand how scientific facts and ideas were established. Scientific practices include; building explanatory ideas or theories, analyzing data, synthesizing ideas, critiquing scientific arguments, and communicating results (French, 2005). Additionally, the development of a learning environment has been shown to be an integral part of developing students' science practices (Wu and Krajcik, 2006). Research shows that explicit instruction should be used to help students make connections across different activities and learning experiences.

Novice or preservice teachers need to develop the skills to be able to connect contradictory bits of isolated facts and organize them in the context of core principles and theories (Crawford, 2007). Research has shown that students have significantly higher levels of knowledge integration and understanding when their teachers value inquiry teaching strategies (Liu, Lee, and Linn, 2010). Lesson planning should reflect multiple inquiry approaches so that students can use those facts to develop their own theories. Research has shown that preservice teachers who experience inquiry-based teacher preparation programs are more likely to develop lesson plans and teach in an inquiry manner that is aligned with scientific practices (Schwarz, 2009). Preservice teachers can assess existing curricula and create inquiry-based lessons if they learn how to teach in an inquiry manner (Forbes and Davis, 2010). Research has shown that students learn when they develop models or when teachers use models to explain difficult concepts (Van Driel and Verloop, 1999). Other research has shown that using problembased strategies helps students identify problems and solve them in an authentic manner (Chin and Chia, 2004).

Research has shown that students can connect science topics and develop theories best when they are given opportunities to collect, analyze, and interpret data. The formulation of theories is reliant on the collection and interpretation of evidence. Designing experiments is an important practice in which students identify relevant variables, distinguish types of variables, and control variables to determine causation. The practice of identifying relationships and patterns is an integral aspect of science, and researchers have shown that students who use data to make relationships and identify correlations are able to recognize casual mechanisms and natural patterns. Minner, Levy, and Century (2009) conducted an analysis of inquiry-base studies from 1984 to 2002, and concluded that there is a positive trend favoring inquiry-based instructional practices, including drawing conclusions from data.

NSTA Standard 3: Learning Environments

Throughout the history of education in general, the method by which instruction should be successfully delivered has been in consistent debate. In science education, the pendulum has swung consistently back and forth from direct instruction and memorization of facts to a more discovery or inquiry based approach. Early on, what worked in educational instruction was largely related to what students learned and how successful they were in mastering the concepts presented. The essential elements of instruction, the in-service program resulting from the theories resulting from Hunters (1982) work, focus on what many term as a "seven step" model that describes one type of teaching that quickly turned into a checklist used for teacher evaluation. Even though Hunter herself advised that not every element was required in every lesson, the structure was viewed as a valuable planning tool, even in science teaching (Hunter, 1991).

The lens through which instruction is viewed has changed from not only focusing on the student as learner, but also the teacher as instructional planner. This paradigm shift was realized and clearly articulated by Bransford, Brown and Cocking (2000) when they stated "educational goals for the twenty-first century are very different from the goals of earlier times" (p. 131). This shift in perception of what is important, emerged onto the science education scene with the publication of several documents from a variety of different organizations, (Project 2061, 1990; National Research Council, 1996; National Commission onMathematics and Science Teaching for the 21st Century, 2000) all of which pointed to a need for reform in science education, a shift in emphasis was urged to a more student "inquiry" format. The National Science Education Standards (1996) assert that "in the same way that scientists develop their knowledge and understanding as they seek answers to questions about the natural world, students develop an understanding of the natural world when they are actively engages in scientific inquiry – alone and with others" (p. 29). This philosophy has resulted in a movement toward standards-focused and inquiry-rich instruction.

Cobern et al (2009) stated that "inquiry teaching rather than direct is most in keeping with the widely accepted constructivist theory of how people learn" (p. 2) which is what Bransford Brown and Cocking also purport. Additionally, the need for learner-centered environments has emerged with a goal of making students more active, involved learners rather than passive receivers of information. Bransford, Brown and Cocking (2000) explain that "teachers who are learner centered recognize the importance of building on the conceptual and cultural knowledge that students bring with them to the classrooms" (p. 134). Standards based, inquiry instruction is such a learner centered environment when developed properly, thus allowing teachers to design an instructional situation that assists in meeting all aspects of this standard.

Research has suggested that teaching for inquiry should result in the students' ability to engage in the following five features of inquiry when compared to traditional classroom instruction: 1) engaging scientific questions, 2) priority to evidence, 3) explanations from evidence, 4) evaluation of explanations, and 5) communicate and justify explanations (Guess-Newsome, Luft and Bell, 2009, p. 4). We know from research that the inquiry approach can cause students to be “highly engaged and excited about learning and they are gaining a deeper understanding of concepts, improving their use of process skills and developing competency in the inquiry processes advocated in the National Science Education Standards” (Stepans and Schmidt, 2009, p. 57). Frequently, inquiry must include the kind of environment in which the scientist conducts their work. As one writer puts it, “the nature of science is closely interconnected with the knowledge and processes of science and is best taught in these domains (Bell, 2008, p. 268). Further, such inquiry must be conducted using safe and ethical means (NSTA, 2010a, and 2010b). Whether it is the bench-lab setting in chemistry or the natural environment in earth science, laboratory or field work should be a central part of the student’s experience in science learning (Bybee, Powell and Trowbridge, 2008; NSTA, 2010c).

Science teachers should demonstrate their abilities in writing individual daily lesson (short-) as well as unit and year-long (long-range) plans. The guiding principles for the content of, as well as the pedagogical approaches to this planning can come from The National Science Education Standards. These standards are more like policies and are not an attempt to establish a national curriculum. However, they do set a direction, establish a focus with wide acceptance, and define competencies and expectations for all students (Bybee, Powell and Trowbridge, 2008). Furthermore, the NSES (1996) does provide a structural outline that allows for the alignment of the curricular content, instructional planning, design of the learning environment (instruction), and the assessment of student understanding.

Planning is important, and the related standards are explicit regarding successful standards-based and inquiry-rich lesson plans (Bushman and Goldman, 2003). Planning extends to assessment as part of the curriculum - instruction – assessment cycle. It should be assessment that drives the decisions as to what the teacher does next. Questions such as “Are my students weak or strong in the pre-requisite information they need before I continue?” and “Which learning standards have my students mastered?” will help define appropriate nextsteps and will ultimately maximize the student’s potential for achievement on all-too prevalent high-risk testing (Bybee, Powell and Trowbridge, 2008). In the use of assessment as a source of data to define what comes next, the focus of assessment in an inquiry classroom is on what learners are doing, not on what their teacher is doing (Meadows, 2009, p. 5).

As one report urges, “…we have learned much in the past generation about what works in mathematics and science education – about rigorous curriculum, high standards, effective teaching methods, challenging assessments, and how young people learn. …We now have the chance to bring this knowledge together in a mathematics and science education effort that will serve as a powerful tool for change” (National Commission on Mathematics and Science Teaching for the 21st Century, 2000, p. 16).

NSTA Standard 4: Safety

Safety is a concern that is an important part of the preparation program for prospective teachers of science. The National Science Education Standards (National Research Council (1996) states: “Safety is a fundamental concern in all experimental science. Teachers of science must know and apply the necessary safety regulations in the storage, use, and care of the materials used by students” (p. 44). This is especially so in this period of inquiry-based science learning and teaching (Gerlovich, McElroy, Parsa and Wazlaw, 2005). So important is safety, that one text warns that “while safe practices support inquiry-based science, it is totally inappropriate to let students learn by trial and error when it comes to matters of safety” (Kwan and Texley, 2002, p. 7).

It is incumbent on programs that prepare science teachers to recognize that all teachers (including new teachers on their first day of teaching) have a legal responsibility to provide a “duty of care” for students. The duty of care responsibilities relative to students and other school employees are described in three categories: Duty of Instruction, Duty of Supervision and Duty to Maintain Equipment and facilities (Science and Safety: Making the Connection, 2000).

Teaching the students is an important aspect of the duties that are faced by science teachers (Barrier, 2005). Case law confirms that each of these duties must be maintained at appropriate levels. Ryan (2010) points out that teachers must comply with their duty to instruct, especially (but not exclusively) when using dangerous chemicals (as in Mastrangelo v. West Side Union High School District), or in establishing, teaching, and enforcing rules (as in Scott v. Independent School District #709).

Ryan (2010) emphasizes the duty to supervise students at a level appropriate to the activity. For instance, this area includes the need to carefully monitor any lab activity for compliance with procedure (as discussed in Connett v. Fremont City School District) and to be physically present especially if there is reasonable cause to foresee a dangerous situation (as in Ohman v. Board of Education of New York City). Implicit in this (and the next) duty is for science teachers to be prepared to respond appropriately to safety plans implemented by the school district and to work with their administration to assure that all is in order (NSTA, 2000).

The duty to maintain equipment is also described by Ryan (2010) with supporting case law. A teacher must carefully select activities that take into account the facilities in which the teaching occurs (as discussed in Bush v. Oscoda Area Schools), appropriately store and handle chemicals (as discussed in Reagh v. San Francisco Unified School District), and ensure that laboratory equipment is in good repair (as discussed in Station v. Travelers Insurance Co.). In a position statement, The National Science Teachers Association (NSTA) states “that developmentally appropriate laboratory investigations are essential for students of all ages and ability levels (NSTA, 2007a). In another position, NSTA also asserts that “as professionals, teachers of science have a duty of care to ensure the safety of students, teachers, and staff.”

going on to state that “science educators must act as a reasonably prudent person would in providing and maintaining a safe learning environment for the students” (NSTA, 2007b).

Yet according to Kaufman (2011), at least 21 students have been injured in high school laboratories from 2000 to2010. Kaufman investigated the causes of 1,000 chemical accidents that occurred in educational institutions, and found that the accident rate in schools was 10 to 50 times greater than the rate incurred in the chemical industry. In addition, accidents were more likely to occur in the classroom of a teacher with less than five years of experience.

Although many science classrooms use live animals, future science teachers need to be enabled to properly care for and use those animals in an ethical, humane manner. “NSTA supports including live animals as part of instruction in the K-12 science classroom because observing and working with animals firsthand can spark students’ interest as well as a general respect for life while reinforcing key concepts as outlined in the NSES (NSTA, 2005). One expert in the area states “Keeping live animals in the classroom of laboratory makes science come alive for students.” But Roy cautions that “Teachers are expected to be knowledgeable about proper care of organisms under study and the safety of their students” (Roy, 2004, p. 10) In linking the issues of animals in classrooms to the duty of science teaching, issues involving ethical, respectful and safe handling of animals extends to even those animals being used in dissection (Roy, 2007).

Standard 5: Impact on Student Learning

The capacity to design, develop and utilize assessment increases teacher candidate ability to evaluate and measure evidence of student learning as well as effectively inform and monitor his/her own instruction. “Your use of assessment as a teacher will assist you to stand back and look at the experience of a lesson or an interaction, but it also provides direction for the next experience. And so, assessing also brings you as a teacher back to planning” Alverno, 1996, p. 39). The ability to create authentic formative and summative assessment experiences based on standards is necessary if the teacher wants to generate and use data. The data is used to gauge student understanding that will, in turn, guide a teachers instructional decisions. (Darling-Hammond, 2006). Using assessment data will enable the teacher candidate to reflect on the students' command of content and process, monitor student progress in developing conceptual understanding, and plan how to proceed. The teacher preparation program is the vehicle through which the teacher candidate gains a knowledge base of content and engages in pedagogical experiences that will serve them well once they transition to a teacher in-service. Being immersed in a program that supports gaining knowledge of assessment design and implementation is essential to candidates becoming more effective practitioners of science teaching.

The ability to use assessments for professional and pedagogical purposes is recognized as a critical element of teaching. Bloch, and Laurie (2009) state, “Central to planning effective science units and lessons is identifying from the beginning how students will be assessed” (p. 218). Traditionally, assessment (summative) was used to indicate the end of learning and reveal evidence of what students learned and what they did not learn. This view of assessment resulted in a low-level of learning that focused on the “right” answer as revealed by rote learning. When the focus is on rote learning, science becomes an encyclopedia of facts that has little interest to the students. A more robust curriculum with assessments that are not limited to low-level cognitive tests allows for a subject that can be more interesting to a greater number of students (Block and Laurie, 2009). This curriculum would include such factors including student recognition of science as a human endeavor and the ability to identify science versus non-science. The teacher in return would need to use data from formative assessment to reflect on whether students did, in fact, learn science (National Research Council [NRC], 1996).

The implications and impact of assessments on classroom instructional practice can only be determined after making a clear distinction between summative and formative assessments and their prescribed uses. “Formative assessment is a planned process in which assessment elicited evidence of students’ status is used by teachers to adjust their ongoing instructional procedures or by students to adjust their current learning tactics” (Popham, 2008). In contrast, summative assessment is usually standard based and is administered at specific points of time throughout curriculum implementation, and it identifies what students know or do not know as it relates to the curriculum/standard. In addition, summative assessments can be used for a variety of purposes such as grading, placement and accountability (NRC, 2001). As suggested by the National Science Education Standards all aspects of science achievement should be monitored through a variety of assessment methods (National Research Council, 1996). Thus, using data will enable the teacher to reflect on both content and process to appropriately monitor student progress in science and plan how to proceed.

As the capacity level to design, develop and utilize assessment increases teacher candidates will be better able to evaluate and measure evidence of student learning as well as to effectively inform and monitor their own instruction. "Your use of assessment as a teacher will assist you to stand back and look at the experience of a lesson or an interaction, but it also provides direction for the next experience. And so, assessing also brings you as a teacher back to planning" (Alverno, 1996, p. 39).

The pre-service teachers ability to design authentic performance tasks and construct inquires based on learning goals and outcomes to include real world scientific phenomena is essential in demonstrating knowledge of P-12 students ability to distinguish between science and nonscience. The National Science Education Standards stated, "Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism (NRC, 1996, p. 201). It becomes necessary for the teacher to assess in order to determine how the student is thinking. "As students develop and … understand more science concepts and processes, their explanations should become more sophisticated … frequently reflecting a rich scientific knowledge base, evidence of logic, higher levels of analysis, and greater tolerance of criticism and uncertainty" (NRC, 1996, p. 117). As the student and teacher work together to correct misconceptions and build a more accurate and deep understanding of science, the skills learned become as important as the science itself (Atkin, 2002).

In addition, teacher candidates must be taught to identify, and expertly extract relevant evidence that supports students' comprehension of a scientific concept as it is being formulated. Candidates must gather information regarding what their students learned and then ask questions about the choice of methods and strategies utilized (Bransford, et.al, 2005). Consequently, the data provided by the evidence of student learning should be appropriately managed and a plan established to inform the teaching and learning of science including content specified in national standards. Included in the National Science Education Standards (1996) is that "teachers of science should not assume that students have an accurate conception of the nature of science in either contemporary or historical contexts" (p. 170). Understanding the history and nature of science will enable the students to recognize science from non-science, and leading to an understanding of "what science and technology can and cannot reasonably contribute to a society" (NRC, 1996, p. 171).

Standard 6: Professional Knowledge and Skills

Professional development needs to focus on two dimensions shown to be important. First, science teachers need to learn science content to facilitate inquiry into subject area learning in depth. Second, science teachers need to engage in professional development to enable their use of inquiry learning methods with their science classes (Bybee and Loucks- Horsley, 2001). The degree to which the breadth and depth of content knowledge alone is responsible for excellence in the classroom is highly debated in the literature. Some research shows that content knowledge is the single most important factor in the preparation of teachers. Yet other research casts a shadow on the importance of content knowledge alone (Grossman, Schoenfeld and Lee, 2005). The issue of professional development seems to be related directly to student achievement. “The CCSSO meta-analysis of studies of teacher professional development programs in mathematics and science found that 16 studies reported significant effects of teacher development on improving student achievement” (CCSSO, 2009, p. 27). The Standards for Science Teacher Preparation recognize that a broad and deep understanding of content must be accompanied by explorations of how the content can be put into practice as the educator adopts their role.

The American Council on Education (2002) found that “effective teachers demonstrate command of the subject matter they teach, strong preparation in effective pedagogical practice, and high academic performance” (p. 5). While research is conflicted regarding the importance of content alone, the delivery of content in the teaching process must be accurate and effective, extending from not only content alone, but also pedagogical practice. Without an ability to communicate within their role using the content, the professional educator would be ineffective. Therefore, continued professional development is found to be most effective when it includes both content and pedagogical content knowledge (Grossman, Schoenfeld and Lee, 2005; Bybee, 2010).

Assessment of content alone has it historical roots in GPA and in tests of content that the teacher was to teach (Ravitch, 2002). Such tests were one-time events and have, over time, become a commonplace requirement for licensure in most states in the union. Additionally, the issue of GPA as an indicator of content and pedagogical content knowledge is subject to grade inflation (Abbott, 2008). Although these measures may be sufficient to measure entry level knowledge, there is a need to assure that every candidate demonstrates that their content will remain accurate given the ever-changing knowledge bases of science and science teaching. Good professional development will “allow teachers to rethink their notions about the nature of science, develop new views about how students learn, construct new classroom learning environments, and create new expectations about student outcomes” (Rhoton and Bowers, 2001, p. iv).

Reflection will enable the candidate to improve their practice based on experience. Reflection must develop the ability to utilize systematic, purposeful inquiry and critical reflection to learn from one’s teaching (Darling-Hammond, 2006). Stiles and Mundry (2002) state that “integrating pedagogical content knowledge and science content knowledge into the professional of teaching is obviously critical" (p. 147). According to the National Science Education Standards (1996), "beginning with preservice experiences and continuing as an integral part of teachers' professional practice, teachers have the opportunity to work with master teachers and reflect on teaching practice" (p. 5). Considering the issues of professional development and reflection together makes sense.

Professional development has long been identified as necessary for the successful implementation of reform. "Professional development efforts should connect to classroom practice, help teachers learn their content in new ways, challenge pedagogical beliefs and practices, promote incremental change, provide for collaboration, and exist in a climate of sustained support" (Guess-Newsome, 2001, p. 98). Often in spite of the demands of the present era of accountability and its emphases on related testing programs, we must maintain the focus on professional development to assure that the beginning science educator helps to professionalize science teacher education. Professional development remains a necessary prerequisite.

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