❖Council of Chief State School Officers❖

MODEL STANDARDS IN SCIENCE FOR BEGINNING TEACHER LICENSING AND DEVELOPMENT: A RESOURCE FOR STATE DIALOGUE

Developed by
Interstate New Teacher Assessment and Support Consortium
Science Standards Drafting Committee

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Executive Summary

<u>Introduction</u>

In the *Model Standards in Science for Beginning Teacher Licensing and Development [standards]* the term standard describes a **vision** of education policy and practice in which teachers have the knowledge, skills, and dispositions for teaching science that enable them to in turn enable all students to attain scientific literacy. Scientific literacy has three components. First, students achieve understanding of important science ideas, with emphases on understanding and important ideas. Next, that this understanding is achieved through inquiry. Finally, students are able to apply both science ideas and scientific inquiry as they consider natural events and phenomena, especially events and phenomena that influence their personal lives and decisions. This concept of scientific literacy is consistent with the vision of the *National Science Education Standards* (NRC, 1996) and Project 2061 (AAAS, 1989, 1993, 1997, 2001). The *Model Standards in Science for Beginning Teacher Licensing and Development* also set **criteria** that describe the knowledge, skills and dispositions of the beginning teacher of science. The *Core Principles of the Interstate New Teacher Assessment and Support Consortium [INTASC]* (INTASC, 1992), which these standards explicate for teachers of science, are designed to complement the dimensions of masterful teaching enacted by National Board for Professional Teaching Standards (1991). Each of the ten principles that constitute the *Standards* in science highlights a significant aspect of the practice of science teaching. Taken together, the principles are more than the sum of their parts, portraying science teaching as grounded in theory and elegant in practice.

One of the practical elements of teaching is context. One component of context is the grade level of the students being taught. Students have the right to the opportunity to learn science at **all** grade levels. However, the breadth, depth and complexity of that science increase as students' understanding and experience increase. These *Standards* are intended to describe the practice of all teachers who teach science at any grade level, K-12. However, some teachers primarily teach courses specifically intended to enable students to describe, explain and predict natural phenomena. Schools and districts usually identify these as science courses and the teachers as science teachers. In this document, the designation science teacher applies to teachers of science courses, usually those who teach students in grades 7-12. Other teachers teach an array of school subjects such as mathematics, reading, social studies, as well as science. These generalists usually teach students in grades K-6. In this document, the phrase teacher of science includes teaching generalists who teach science as well as designated science teachers. While the difference may seem semantic, the terms signal important differences in the knowledge, skills and dispositions.

The vision of science teaching that informs the *Standards* assumes teaching is complex. Consequently, this or any set of descriptions of quality teaching is in tension. On the one hand the description might be reduced to numerous isolated statements that strip teaching of its dynamic, contextual aspects. On the other hand, the description could be so elaborate that the teaching appears idiosyncratic and unprincipled. Our aim was a middle position. The INTASC core principles and the explication of these principles for teachers of science have been written by and for teachers. They have high face validity -- teachers recognize the principles as describing what they do and what they know. These *Standards* seem to be neither too simplistic nor too complex. However, to maintain the spirit of complexity in these *Standards*, the standards are cross-referenced to one another. Further, two forms of illustrative examples are presented. Short illustrations are placed near the text on the principles, while longer stories of science teaching, based on actual classroom experiences, are found toward the end of the book.

Principle 1: CONTENT

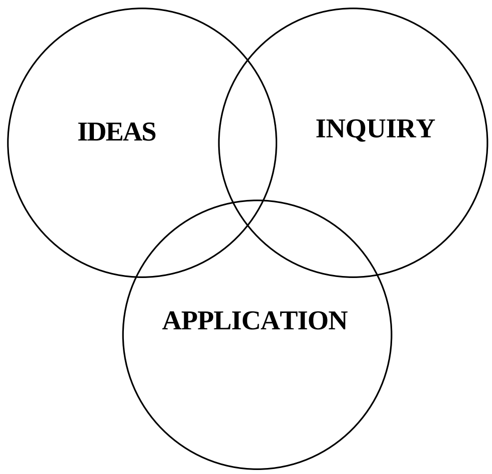
The teacher of science understands the central ideas, tools of inquiry, applications, structure of science and of the science disciplines he or she teaches and can create learning activities that make these aspects of content meaningful to students.

The INTASC Science committee is not the first to explicate science standards for teachers and for students. Both Project 2061 of the American Association for the Advancement of Science [AAAS] and *National Science Education Standards* developed by the National Research Council (1996) are credible efforts that are similar in scope and intention. In order to signal that the current reform in science education is a consistent effort, the content that all teachers of science understand and are able to do is derived from the *National Science Education Standards* [NSES]. The *NSES* describes what all students should understand and be able to do in science to become scientifically literate citizens. The science content which students need to know provides the framework for the science content that teachers need to know. The science content in the *NSES* is organized into eight categories:

- Unifying Concepts and Processes (for example, evidence, models and explanations),
- Inquiry (for example, recognize and analyze alternative explanations and models),
- Physical Science (for example, motions and forces and chemical reactions),
- Life Science (for example, molecular basis of heredity),
- Earth and Space Science (for example, energy in the Earth system),
- Science and Technology (for example, design a tool to increase accuracy in evidence),
- Science in Personal and Social Perspectives (for example, natural and human-induced hazards),
- History and Nature of Science (for example, changes in explanation over time).

Throughout these *Standards* these eight categories of science content are further organized into three larger interrelated categories: ideas, inquiry and application. Ideas include the facts, ideas, concepts, laws, theories and models that scientists and students come to understand as they describe, explain and predict natural phenomena. Important science ideas are found in the Physical Science, Life Science and Earth and Space Science categories from *NSES*, as well as aspects of Unifying Concepts and Processes and History and Nature of Science categories. The *NSES* calls for students to come to understand important ideas. Inquiry includes thinking skills such as asking questions, hypothesizing, reasoning, arguing from evidence, generalizing, and revising models as well as manual skills that are used by scientists such as using instruments accurately. Inquiry includes the Inquiry category as well as aspects of Unifying Concepts and Processes, Science and Technology and History and Nature of Science categories. Science application includes human aspects of science such as the relationships between science and society, the history of science and technological design. Applications are found in the Science in Personal and Social Perspectives category as well as aspects of Unifying Concepts and Processes, Science and Technology, and History and Nature of Science categories.

However, knowing the science content intended for students described in the *NSES* is necessary but not sufficient for teachers. Teachers of science need to have a depth of understanding of this content, know how the content develops conceptually and chronologically in the understanding and ability of students, and how the content of each category is related to the content of the others and to important content of other school subjects. While all teachers of science (Grades K-12) have the depth and breadth of understanding described in *NSES*, science teachers (Grades 7-12) have even greater depth of understanding in at least one science discipline. All science teachers also have had the opportunity to participate in scientific inquiry, beyond what occurs in the typical laboratories of higher education. Such an experience of scientific inquiry is a prerequisite to assisting students as they come to understand science as inquiry.



SCIENCE CONTENT

<u>Principle 2: STUDENT LEARNING AND DEVELOPMENT</u>
The teacher of science understands how students learn and develop and can provide learning opportunities that support students' intellectual, social, and personal development.

Teachers of science recognize that learning is an active process in which students engage. They further recognize that science activities by themselves are not sufficient to promote student understanding and ability. Activities need to be selected to match with a wide range of learning outcomes. Teachers know and consider the misconceptions in science that are commonly held by students of the age they teach. Teachers of science adapt instructional activities to provide students opportunities to build on their present understanding as they create new understanding. They adapt age-appropriate instructional activities that focus on important science content that are meaningful to students.

Principle 3: STUDENT DIVERSITY

The teacher of science understands how students differ in their approaches to learning and creates instructional opportunities that are adapted to diverse learners.

Teachers of science realize that students bring a wealth of prior experience to their science learning. Students also bring a variety of interests and needs. Teachers understand that the collaborative nature of scientific inquiry and the aim to develop the classroom as a collaborative community of learners provides opportunities to capitalize on the diversity among students. They know that all group work is not necessarily collaborative while a student working alone may be engaged in collaboration. Encouraging collaboration in science is one strategy that allows students to acknowledge, value and respect the expertise and diversity of all learners. Teachers have an ever-growing repertoire of culturally and socially relevant examples, analogies and metaphors to enable them to support the science understanding of all students. They know that they must be willing and able to adapt laboratory and field-based activities to provide a safe and equitable learning experience for all students including those with special needs.

Principle 4: INSTRUCTIONAL VARIETY

The teacher of science understands and uses a variety of instructional strategies to encourage students' development of critical thinking, problem solving, and performance skills.

Teachers of science understand that the nature of science, how students develop and learn, and the variety of experiences and interests that students bring to class all drive the selection of science activities that focus on understanding important ideas, inquiry and application. Teachers strive to create a balance between a variety of instructional approaches. Teachers of science know that whether reading a text, studying a research article, designing an investigation, organizing data on a computer, defending an idea or presenting conclusions during an exhibition, students can focus on science understanding, inquiry and application.

Principle 5: LEARNING ENVIRONMENT

The teacher of science uses an understanding of individual and group motivation and behavior to create a learning environment that encourages positive social interaction, active engagement in learning, and self-motivation.

A learning environment that fosters the development of science understanding, inquiry and application for all students includes both the psychosocial and the physical learning environment. Teachers of science select and adapt curricula that are appropriate to the needs, interests, abilities, and prior experiences of all students. They provide opportunities for students to express their developing science understandings in an environment that is both respectful and challenging. They recognize that organized planning and placement of materials and information are necessary to permit active engagement of students in safe and productive learning. The science learning environment must be physically safe but sufficiently unrestricted to allow for inquiry. Teachers therefore establish and enforce routines and rules for safe and effective activities. While the classroom is vibrant with living and non-living science artifacts, teachers of science know and observe the regulations and policies for the safe and ethical treatment, maintenance and storage of organisms, science specimens and scientific data.

<u>Principle 6: COMMUNICATION</u>

The teacher of science uses knowledge of effective verbal, nonverbal and media communication techniques to foster active inquiry, collaboration, and supportive interaction in the classroom.

Teachers of science appreciate the particular importance of precision and accuracy of language and of mathematics in describing natural phenomena and making scientific explanations. They know that some words have different or more precise meanings in science than they do in common usage. Teachers of science know how and when to ask divergent questions that require explanation and prediction. Teachers of science provide students with opportunities to gather, organize, interpret and present data. They require students to record their work using multiple representations such as models, concept maps, diagrams, graphs, tables and charts. Students are encouraged to present their understanding in various formats. Teachers foster student reflection about how a task was done, why the task was done and how they have developed an understanding of the scientific ideas.

<u>Principle 7: CURRICULUM DECISIONS</u>

The teacher of science plans instruction based upon knowledge of subject matter, students, the community, and curriculum goals.

Teachers provide students with opportunities to experience the full extent of science content: the synthesis of important science ideas, inquiry and application. They rely on national documents such as the *National Science Education Standards* and the publications of Project 2061 as well as state and local curriculum requirements to select science content for instruction. As members of a school community, they are aware of the intended outcomes of the school curriculum and how those are being met through the local science program. Teachers of science know that science happens all the time and in many places. They are aware of current topics are that are holding students' interest. Teachers encouraging visits to zoos, museums, science centers and places where science is happening. They also make use of the resources of the larger community such as parents and business and industry in planning the curriculum.

<u>Principle 8: ASSESSMENT</u>

The teacher of science understands and uses formal and informal assessment strategies to evaluate and ensure the continuous intellectual, social and physical development of the student.

Teachers of science know that assessment, evaluation and grading represent three separate, albeit closely related activities of gathering information, making a judgement about quality and reporting that judgement. Teachers of science know what information counts as evidence of attainment in science and how to gather that evidence. They use multiple forms of assessment including research papers, portfolios, and performance tasks complementing more traditional forms such as multiple choice tests, essay answers and laboratory reports. Teachers consider how continuous and on-going assessment supports instruction and enhances student learning. Consequently, they design assessment and instruction simultaneously so that the goals of each are congruent with each other. Teachers provide timely feedback to students about their achievement on assessment tasks. Teachers of science value the use of self-assessment as an important component of a science program. They also gather information on the opportunities students have had to achieve understanding.

Principle 9: REFLECTIVE PRACTITIONERS

The teacher of science is a reflective practitioner who continually evaluates the effects of his/her choices and actions on others (students, parents, and other professionals in the learning community) and who actively seeks out opportunities to grow professionally.

Teachers of science reflect on their teaching and its effects on student learning by monitoring and evaluating their practice. Self-reflection, going beyond description to include analysis, provides a mechanism for teachers to gauge their growth in all aspects of their professional life including knowledge of science content, students, pedagogy, learning and assessment. In conjunction with a school professional development program, teachers of science develop a personal professional development plan. They conduct classroom-based research to better understand the effect of their teaching on student learning and they understand the value of peer coaching and mentoring.

Principle 10: COMMUNITY MEMBERSHIP

The teacher of science fosters relationships with school colleagues, parents, and agencies in the larger community to support students' learning and well being.

Teachers of science are members of the school community. As such they work with other teachers and administrators to develop the school as a community of learners and they contribute to the well being of the school community by participating in school activities. Teachers are aware that their classroom learning community is situated within the larger school community and that the school community in turn is part of the larger educational system. They work with students, colleagues, administrators, parents, and other community members to provide opportunities that allow students to enhance their knowledge of science and utilize that knowledge within the larger community. Teachers of science recognize that being a professional requires being involved in professional activities beyond the classroom and school. Also they know and obey the policies and regulations for the safety and welfare of students in a science classroom.

Model Standards in Science for Beginning Teachers

Numerous organizations and individuals have contributed to the vision of science education that provides the focus for current and future policy and practice. This vision describes an aim of scientific literacy for all Americans. Four features characterize this vision. First, science education is for all students. Because science is intriguing in and of itself as well as being useful for personal decisions and necessary for making informed political decisions and because being scientifically literate contributes to economic productivity, all students should know science. Further, science for all supports the belief that, given the opportunity, all students can attain understanding of science.

The second feature of the current vision of science education is understanding. Understanding implies that all students know rich, interrelated structures of facts, concepts, laws, theories and models, referred to in this document as ideas. Understanding further implies that this complex knowledge structure enables students to describe, explain and predict natural events and phenomena. Understanding also implies that students know the origin of these ideas and why they are powerful in describing, explaining and predicting. Finally, understanding implies that students are able to use these ideas in new and diverse situations. Slogans like "less is more" and "depth over breadth" are commonly used to highlight this focus on understanding. Practitioners and policy makers alike acknowledge that developing understanding is a strenuous and time-consuming task for both students and teachers. Therefore, the focus on understanding leads to including fewer but more complex interrelated ideas in the study of school science. These complex structures of ideas frequently transcend a single science discipline and are as diverse as modeling, energy, variation, plate tectonics and the atomic theory. The complex structures of ideas that students should come to understand have variously been referred to as "fundamental understandings," "big ideas," and "important topics."

The third feature of the current vision of science education is inquiry. Inquiry describes what scientists do and what students do as they develop understanding of important ideas in science. Inquiry implies the familiar processes of science such as describe and hypothesize, but goes beyond these processes to include abilities such as problem solving and critical thinking, reasoning, argument from evidence, and persuasion. Inquiry proceeds from and leads to understanding science ideas. Inquiry helps students understand what counts as knowing in science. Understanding science through inquiry is one hallmark of scientific literacy.

The final feature that characterizes the vision for science literacy is that people do science. Therefore, science applications to personal and public life requires cooperation and communication, can cause dilemmas that entail ethical consideration, and has a history with heroes.

The Science Committee of the Interstate New Teacher Assessment and Support Consortium [INTASC] quickly reached a consensus that the vision of science education would be best served by closely aligning the *Model Standards for Beginning Science Teachers* with one of the current reform documents in science education. We chose the *National Science Education Standards*. Therefore, each principle of the beginning science teacher standards closes with a quote from the *National Science Education Standards (NSES)* to illustrate the congruence of the vision of INTASC with the current beliefs, goals and practices in science education. Also, Principle 1 on science content is based on and derived from the *NSES*. The Committee recognizes that many schools, districts and states have already expended extensive resources to align their goals for science education with Project 2061, including *Science for All Americans, Benchmarks for Science Literacy and Resources for Science Literacy*. Both the *NSES* and Project 2061 labored diligently for many years through multiple cycles of writing, public review and revision to describe the current vision of science education. *Resources for Science Literacy,* released by Project 2061, highlights the greater-than-90% congruence between these two projects as they name the important ideas in science. Those who use these beginning teacher standards may access this comparison in Resources for Science Literacy.

In addition to a growing consensus about the vision of science education for scientific literacy, there is a growing consensus that science content (with the curricula derived from this content), science teaching and learning, and science assessment are three cornerstones on which this vision of science education is built. While it becomes increasingly difficult to separate content, teaching and learning, and assessment in the practice of science teaching, it remains equally necessary to separate them in setting and describing standards for that practice. Therefore, although presented one-by-one, the principles for beginning science teachers are frequently crossed referenced with one another and with stories of science teaching to illustrate the standards.

The science teaching standards are expressed in descriptive rather than prescriptive language to reflect the conviction that the profession of teaching cannot be strengthened by telling teachers what they should or must do. We believe that the profession is made stronger by portraying in clear and specific terms what it means to be a well-prepared teacher of science.

The INTASC Science Standards are intended to describe the practice of all teachers of science, grades K-12. However, some teachers teach courses specifically intended to enable students to describe, explain and predict natural phenomena. Schools and districts usually identify these as science courses. Science courses may have traditional names like biology or physics, or have names indicating greater integration of science content, such as environmental sciences or molecular biochemistry. In this document, the designation science teacher applies to teachers of science courses, usually those who teach students in grades 7-12. Other teachers teach an array of school subjects such as mathematics, reading, social studies, as well as science. These generalists usually teach students in grades K-6. In this document, the phrase teacher of science includes teaching generalists who teach science as well as designated science teachers. While the difference may seem semantic, the terms signal important differences in the knowledge, skills and dispositions.

Principle 1: SCIENCE CONTENT[1]

The *National Science Education Standards (NSES)* (National Research Council, 1996) describe what all students should understand and be able to do in science after 12 years of education. In doing so, they also describe the purpose of the science understandings and abilities for all teachers of science, to be able to provide instruction in science that provides opportunities for students to attain this understanding. The *NSES* provide the foundation for the description of science content for which all teachers of science are responsible.

Principle 1 begins with an outline derived from the *NSES* of the science content all teachers of science should understand and be able to do. However, an outline of content, while necessary, is not sufficient. Principle 1 continues by describing how the understanding and ability of all teachers of science go beyond the outline. Finally, Principle 1 includes a description of the additional understandings and abilities, which are required for science teachers, those who teach science-specific courses.

Principle 1

The teacher of science understands the central concepts, tools of inquiry, applications, structures of science and of the science disciplines (physics, chemistry, biology and Earth and space science) he or she teaches and can create learning experiences that make these aspects of content meaningful to students.

The *National Science Education Standards* organize the content of science into eight categories. The Introduction to the Content Standards of the *National Science Education Standards* states that "None of the eight categories of content standards should be eliminated . . . No standards should be eliminated from a category (p. 111-112)." In understanding the central concepts, tools of inquiry, applications and structure of science, a teacher of science demonstrates understanding and ability about the following science content.

- **Unifying Concepts and Processes**
  - Systems, order and organization
  - Evidence, models and explanation
  - Change, constancy and measurement
  - Evolution and equilibrium
  - Form and function (National Science Education Standards [NSES], p. 115)

- **Inquiry**
  - Identify questions and concepts that guide scientific investigations
  - Design and conduct scientific investigations
  - Use appropriate tools and techniques to gather, analyze and interpret data
  - Develop descriptions, explanations, predictions and models using evidence
  - Think critically and logically to make relationships between evidence and explanation

[1] In a manner consistent with the *National Science Education Standards*, the term "science content" is intentionally used to designate scientific inquiry, science subject matter and applications of science. The term "science subject matter" includes the facts, ideas, concepts, laws, principles, theories and models associated with the various science disciplines.

- Recognize and analyze alternative explanations and models
- Communicate and defend a scientific argument.
- Understand about scientific inquiry (NSES, p. 175-176)

- **Physical Science**
  - Structure of atoms
  - Structure and properties of matter
  - Chemical reactions
  - Motions and forces
  - Conservation of energy and increase in disorder
  - Interaction of energy and matter (NSES, p. 176)

- **Life Science**
  - The cell
  - Molecular basis of heredity
  - Biological evolution
  - Interdependence of organisms
  - Matter, energy and organization in a living system
  - Behavior of organisms (NSES, p. 181)

- **Earth and space science**
  - Energy in the Earth system
  - Geochemical cycles
  - Origin and evolution of the Earth system
  - Origin and evolution of the universe (NSES, p. 187)

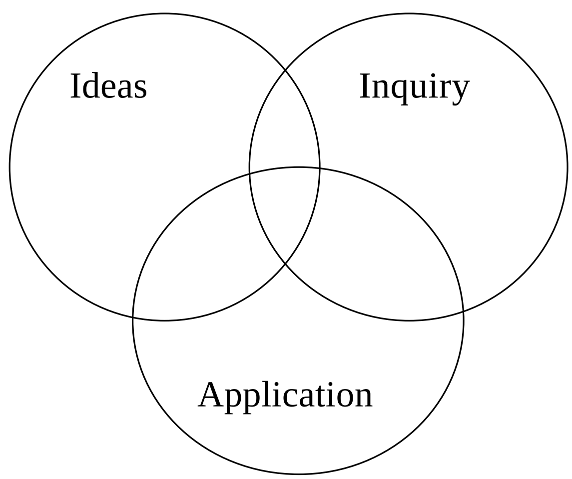
- **Science and technology**
  - Identify a problem or design an opportunity
  - Propose designs and choose between alternative solutions
  - Implement a proposed solution
  - Evaluate the solution and its consequences
  - Communicate the problem, process and solution
  - Understand the relationship between science and technology (NSES, p. 190-191)

- **Science in personal and social perspectives**
  - Personal and community health
  - Population growth
  - Natural resources
  - Environmental quality
  - Natural and human-induced hazards
  - Science and technology in society (NSES, p. 193)

- **History and Nature of Science**
  - Science as a human endeavor
  - Nature of scientific knowledge
  - Historical perspectives in science (NSES, p. 200)

As comprehensive as the eight categories of science content described in T*he National Science Education Standards* are, some readers find the number daunting. Therefore, other organizational strategies have been proposed to represent the content of science. A drawing of three overlapping circles is one scheme frequently used to represent the ideas, inquiry and application of science. Ideas include the facts, ideas, concepts, laws, theories and models that scientists and students come to understand as they describe explain and predict natural phenomena. Ideas are both known and understood. The Physical Science, Life Science and Earth and Space Science categories from *NSES*, as well as aspects of Unifying Concepts and Processes and History and Nature of Science. Inquiry includes the thinking skills such as asking questions, hypothesizing, reasoning, arguing from evidence, generalizing, and revising models as well as the manual skills that are used by scientists such as using instruments accurately. Inquiry includes Inquiry as well as aspects of Unifying Concepts and Processes, Science and Technology and History and Nature of Science. Science application includes as the human aspects of science such as the relationships between science and society, the history of science and technological design. Application includes Science in Personal and Social Perspectives as well as aspects of Unifying Concepts and Processes, Science and Technology, and History and Nature of Science.

Figure 1 SCIENCE CONTENT



TEACHERS OF SCIENCE

While recognizing that a list of topics that represent the content of science is useful, knowing a list is not sufficient to understand the central concepts, tools of inquiry, applications and structure of science required of a teacher of science. Recall that a teacher of science is anyone who teaches science. The teacher's of science understanding extends beyond the list in three ways. First, the teacher of science has a detailed understanding of each important idea. Second, the teacher understands how an understanding of each idea grows and develops for students across grade levels. Finally, a teacher of science understands how the ideas of science are related to one another and to important ideas in other school subjects.

Depth of Understanding of Important Ideas

To illustrate the depth of understanding of science required for a teacher, four ideas -- one each from the unifying concepts and processes, from inquiry, from subject matter and from the application of science -- are examined.

The unifying concepts and processes of science provide powerful ideas in science because they afford insight and understanding in all science disciplines and in the applications of science. These ideas do not exist independent of subject matter, inquiry and application, but inform all of them. Each of these unifying concepts and processes has a conceptual and a procedural aspect, although one or the other is in the foreground depending on the circumstances. One set of closely related unifying concepts and processes in science is evidence, models, and explanation. The *National Science Education Standards* define these unifying ideas as:

- "Evidence consists of observations and data on which to base scientific explanation. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.
- Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.
- Scientific explanations incorporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logical statements. Different terms, such as 'hypothesis,' 'model,' 'law,' 'principle,' 'theory,' and 'paradigm' are used to describe various types of scientific explanations. (p. 117)."

Still the understanding that a teacher of science has about these unifying concepts and processes goes beyond understanding and being able to use these definitions. A teacher of science understands the relationship between the evidence gathered and the question asked. The teacher understands how to gather, organize, interpret and apply evidence. The teacher is able to judge when evidence constitutes a warrant for a claim and when it does not. A teacher of science recognizes that there are multiple models for the same natural phenomena and that different models are appropriate for different questions and different understandings. The teacher recognizes that all models have limitations. The teacher of science understands that being able to construct explanations is more important than being able to define the term.

Inquiry is central to science; it is what science is all about. Inquiry is what scientists do, what teachers of science understand and are able to do and what students of science are learning to do. Inquiry includes but goes beyond the traditional processes of science such as observe and describe, or compare and contrast. Inquiry implies relying on and adding to the rich body of ideas of science; inquiry includes abilities to reason in multiple ways with and about science ideas; inquiry includes abilities to apply the result of inquiry to new questions and situations.

One of the abilities and understandings of inquiry is to identify questions that guide scientific investigations. When students ask a question, the *National Science Education Standards* expects they should be able to "formulate a testable hypotheses, demonstrate the logical connection between the scientific concepts guiding a hypothesis and the design of the experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations (p. 175)." A teacher of science is able to go beyond this. For example, the teacher understands what constitutes a question that can be investigated using the tools of science and the teacher is able to help students shape such questions.

Science subject matter, the conceptual aspect of science, includes the organized body of facts, concepts, principles, laws, theories and models used to describe explain and predict natural phenomena. This subject matter is the beginning and end of scientific inquiry and the basis of application in science. The cell, an important idea in science, can be used as an example to describe the depth of understanding about one concept that all teachers of science hold. The *National Science Education Standards* explicate what it means to have an understanding of the cell. The subject matter standards for grades 9-12 Life Science state:

> Cells carry on the many functions needed to sustain life. They grow and divide, thereby producing more cells. This requires that they take in nutrients, which they use to provide energy for the work that cells do and make the materials that a cell or an organism needs.
>
> Specialized cells perform specialized functions in multicellular organisms. Groups of specialized cells cooperate to form a tissue, such as a muscle. Different tissues are in turn grouped together to form larger functional units, called organs. Each type of cell, tissue, and organ has distinct structure and set of functions that serve the organism as a whole (NSES, p. 156).

The *National Science Education Standards* go on to state:

> Cells have particular structures that underlie their functions. Every cell is surrounded by a membrane that separates it from the outside world. Inside the cell is a concentrated mixture of thousands of different molecules which form a variety of specialized structures that carry out such cell functions as energy production, transport of molecules, waste disposal, synthesis of new molecules, and the storage of genetic material.
>
> Most cell functions involve chemical reactions. Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules. Both breakdown and synthesis are made possible by a large set of protein catalysts, called enzymes. The breakdown of some of the food molecules enables the cell to store energy in specific chemicals that are used to carry out the many functions of the cell.
>
> Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires.

> Cell functions are regulated. Regulation occurs both through changes in the activity of the functions performed by proteins and through the selective expression of individual genes. This regulation allows cells to respond to their environment and to control and coordinate cell growth and division.
>
> Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.
>
> Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells. In the development of these multicellular organisms, the progeny from a single cell form an embryo in which the cells multiply and differentiate to form the many specialized cells, tissues and organs that comprise the final organism. This differentiation is regulated through the expression of different genes (NSES, p. 184-185).

The teacher of science is able to go beyond these understandings of the cell. The teacher knows, for example, that the DNA containing the information for the synthesis of proteins is located in a structure called the nucleus and that photosynthesis consists of two distinct but closely related chemical reactions, the light and the dark reaction.

The Social and Personal Perspectives of Science, the context and application of science, are also essential for teachers of science. One arena where science in the social and personal world is evident is in the relationship between humans and natural resources. The *National Science Education Standards* indicate what understanding about natural resources might include:

> Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have been and will continue to be used to maintain human populations.
>
> The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources and it depletes those resources that cannot be renewed.
>
> Humans may use natural systems as resources. Natural systems have the capacity to reuse waste, but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically (NSES, p. 168).

The understanding of the teacher of science goes beyond these understandings. For example the teacher is able to quantify the relationship between resources and the population, to analyze resource management on a local and global scale and is aware of scientific issues inherent in debates about sustainability.

We stress that the above examples are no more than that -- examples. They are illustrative of a depth of understanding of a few important science ideas. The teacher of science has understanding and ability consistent with the explication of each of the topics in the list that identifies the important ideas of science outlined for Principle 1.

Development of Ideas in Science

In addition to knowing the important ideas in science and having a depth of understanding about them, a teacher of science also understands how these ideas build on each other as students develop their understanding. It is not sufficient for a teacher to understand the major ideas appropriate to the students he or she teaches. Teachers know which ideas came before others, conceptually and chronologically, and which will follow what is currently being taught. That teachers understand how ideas build on each other in science can be illustrated again using the example of the cell from the *National Science Education Standards*, which was introduced earlier. This development is presented in Figure 2 on the following page.

Relationship among Ideas in Science

For purposes of presentation, the list of topics that identify the important ideas in science are organized into eight categories (Unifying Concepts and Processes, Inquiry, Physical Science, Life Science, Earth and Space Science, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science). The teacher of science has developed multiple rich connections among the ideas of science both within and across categories. The teacher of science understands, for example, that the concept of energy is applicable in all science disciplines. The deep understanding of energy that may have been learned in a physics course is needed to understand chemical bonds (from a chemistry course), which in turn is needed to understand the structure and function of DNA (from the biology course). Two additional examples of relationships of among ideas in science are provided.

The cell in relation to other ideas in science is used to illustrate the relationship between and across ideas in science, one example, understandings about the cell appropriate for grades 9-12 presented in Figure 2, will be used. The illustration is presented in Figure 3. In the first column of Figure 3 the statements about the cell from page 184 of the *National Science Education Standards* are reproduced. The second column contains some phrases from the statement that might provide links across important ideas in science. The third column contains science ideas other than the cell related to that phrase. The final column names the category under which that science idea is listed. For example, the first statement about the cell begins "Cells have particular structures..." The phrase structure has an obvious link with the idea of structures and functions from the category of unifying concepts and processes of science. The astute reader will notice that none of the ideas are selected from the Inquiry category. This is because each of these understandings is developed through inquiry and is required for a solid understanding of inquiry.

The concept of light as it develops and is related to other important ideas in science. The idea of light provides another example to illustrate both the development of an important idea in science and the relationship of that idea to other science ideas. The concept of light is introduced in the Physical Sciences grade K-4: "Light travels in a straight line until it strikes an object. Light can be reflected by a mirror, refracted by a lens or absorbed by an object (NSES, p. 127)." A related topic, objects in the sky, in Grades K-4, Earth and space science states that "The sun . . . [has] properties, locations, and movements that can be observed and described (NSES, p. 134)." One of the properties of the sun is that it emits light.

Figure 2. The Development of an important science idea, the cell.

Understandings appropriate for students in grades K-4	Understandings appropriate for students in grades 5-8	Understandings appropriate for students in grades 9-12
Each plant or animal has different structures that serve different functions in growth, survival, and reproduction.(p. 129)	Living systems at all levels of organization demonstrate the complementary nature of structure and function. Important levels of organization for structure & function include cells, organs, tissues, organ systems, whole organisms, & ecosystems. (p. 156)	Cells have particular structures that underlie their functions. Every cell is surrounded by a membrane that separates it from the outside world. Inside the cell is a concentrated mixture of thousands of different molecules which form a variety of specialized structures that carry out such cell functions as energy production, transport of molecules, waste disposal, synthesis of new molecules, and the storage of genetic material. (p. 184)
	All organisms are composed of cells-the fundamental unit of life. Most organisms are single cells; other organisms, including humans, are multicellular. (p. 156)	Most cell functions involve chemical reactions. Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules. Both breakdown and synthesis are made possible by a large set of protein catalysts, called enzymes. The breakdown of some of the food molecules enables the cell to store energy in specific chemicals that are used to carry out the many functions of the cell (p. 184).
	Cells carry on the many functions needed to sustain life. They grow and divide, thereby producing more cells. This requires that they take in nutrients, which they use to provide energy for the work that cells do and make the materials that a cell or an organism needs. (p. 156)	Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires (p. 184).
	Specialized cells perform specialized functions in multicellular organisms. Groups of specialized cells cooperate to form a tissue, such as a muscle. Different tissues are in turn grouped together to form larger functional units, called organs. Each type of cell, tissue, and organ has distinct structure and set of functions that serve the organism as a whole. (p. 156).	Cell functions are regulated. Regulation occurs both through changes in the activity of the functions performed by proteins and through the selective expression of individual genes. This regulation allows cells to respond to their environment and to control and coordinate cell growth and division (p. 184).
		Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems (p. 184).
		Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells. In the development of these multicellular organisms, the progeny from a single cell from a single cell form an embryo in which the cells multiply and differentiate to form the many specialized cells, tissues and organs that comprise the final organism. This differentiation is regulated through the expression of different genes (p. 184-185).

Figure 3. Relationships among some important science ideas starting with the idea of the cell

Understandings about the cell	Linking Phrase	Related Science Ideas	Category
Cells have particular structures that underlie their functions. Every cell is surrounded by a membrane that separates it from the outside world. Inside the cell is a concentrated mixture of thousands of different molecules which form a variety of specialized structures that carry out such cell functions as energy production, transport of molecules, waste disposal, synthesis of new molecules, and the storage of genetic material.	structure surrounded by a membrane mixture energy production genetic material	Structure & function Evidence, models, & explanation Properties of matter Interaction of energy and matter Molecular basis of heredity Personal health	Unifying Concepts & Process Unifying Concepts & Process Physical Sciences Physical Sciences Life Sciences Perspectives
Most cell functions involve chemical reactions. Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules. Both breakdown and synthesis are made possible by a large set of protein catalysts, called enzymes. The breakdown of some of the food molecules enables the cell to store energy in specific chemicals that are used to carry out the many functions of the cell.	chemical reaction protein catalysts store energy	Chemical reaction Chemical reactions Matter, energy and organization	Physical Sciences Physical Sciences Physical Sciences
Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires.	DNA	Structure and property of matter Science and technology Personal and community health Science as a human endeavor	Physical Sciences Technology Perspectives History
Cell functions are regulated. Regulation occurs both through changes in the activity of the functions performed by proteins and through the selective expression of individual genes. This regulation allows cells to respond to their environment and to control and coordinate cell growth and division.	cell functions respond to environment	Structure & function Behavior of organisms	Unifying Concepts & Processes Life Sciences
Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.	use solar energy	Energy in the Earth system Environmental quality Natural resources	Earth Sciences Perspectives Perspectives
Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells. In the development of these multicellular organisms, the progeny from a single cell from a single cell form an embryo in which the cells multiply and differentiate to form the many specialized cells, tissues and organs that comprise the final organism. This differentiation is regulated through the expression of different genes.	highly organized arrangement	Systems, order & organization	Unifying Concepts & Processes

By grades 5-8, the *National Science Education Standards* place “light” in the physical sciences within the idea of transfer of energy. Three aspects of energy transfer refer to light:

> Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.
>
> Light interacts with matter by transmission (by refraction) absorption or scattering (including reflection). To see an object, light from that object -- emitted by or scattered from it -- must enter the eye.
>
> The sun is a major source of energy for changes on the Earth's surface. The sun looses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared and ultraviolet radiation (NSES. p. 155).

The life sciences at grades 5-8 include a reference to cells carrying on many functions needed to sustain life including providing energy for the work that cells do (NSES, p. 156). This is an early reference to photosynthesis, without using that term. Photosynthesis requires light. The Earth and space sciences refer to global patterns of atmospheric movement, which are influenced by radiation from the sun that influence local weather. The Earth and space sciences also refer to "The sun is the major source of energy for phenomena on the earth's surface such as growth of plants, winds, ocean currents and the water cycle (NSES, p. 161)." In the standards on personal and social perspectives there are references to food providing energy and nutrients for growth and that "internal and external processes in the earth system causes natural hazards (NSES, p. 168)." Each of these references requires an understanding of the phenomena of light as a source of energy.

By grades 9-12, light energy is has become essential in understanding several important science ideas. Standards for physical science includes statements such as:

> Chemical reactions may release or consume energy. . . Light can initiate many chemical reactions such as photosynthesis.
>
> The total energy of the universe is constant. Energy can be transferred by collision in chemical or nuclear reactions, by light waves and other radiations.
>
> All energy can be considered to be either kinetic energy which is the energy of motion or potential energy which depends on relative position; or energy contained in fields, such as electromagnetic waves.
>
> Waves, including sound and seismic waves, waves on water and light waves have energy and can transfer energy when they interact with matter.
>
> Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include. . . Light. . . The energy of electromagnet waves is carried in packets whose magnitude is inversely proportional to the wavelength.
>
> Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at waves corresponding to these amounts (NSES, p. 179-180)."

The life sciences refer to light explicitly or implicitly when describing photosynthesis, energy flow through ecosystems, entropy and enthalpy, energy stored in and released from chemical bonds, complexity of organization, population distribution, and energy flow (See NSES, p. 186). In the Earth and space sciences the idea of light is essential to understand that the earth has internal and external sources of energy and stars produce energy from nuclear reactions (See NSES, p. 189-190). In the standards on social and personal perspectives, light is an aspect of understanding how humans affect the physical and chemical cycles of the earth, environmental quality, and weather as a potential for hazards (See NSES, p. 198-199).

The teacher of science understands these and other relationships between and among ideas in science. We strongly urge every teacher of science, teacher educator, and policy maker to choose one important idea in science and map some of the possible relationships between that idea and the other important ideas in science. Also, the reference section includes books and articles, some of which contain additional illustrations of the interrelationships between important ideas in science.

Relationship between Ideas in Science and Understandings and Abilities in Other School Subjects
Finally, the teacher of science realizes that understanding and ability in science relies on and contributes to understanding and abilities in other school subjects. For example, science questions, well-developed arguments and explanations, models and theories about natural phenomena cannot be articulated without well-developed language arts skills. Evidence cannot be organized, charted and interpreted, and mathematical models cannot be developed and tested without understandings and skills in mathematics. Science cannot be applied to important social issues nor can the relationship between science and society be understood without understanding social sciences. Arguments and explanations are defended with elegance when supported by abilities in the fine arts.

All teachers of science have a rich understanding of important ideas in science, how these ideas develop, how they are related to other ideas in science and to other school subjects. This rich body of understanding is organized in a way that is accessible to the teacher for designing and delivering instruction that enables students to come to understand science. This understanding of the teacher of science is both theoretical and practical. For example, the teacher of science understands why inquiry about some ideas is best conduced through debate while for other topics the best mode of inquiry is an investigation. The practical understanding of the teacher of science might also include, for example, recognizing the many simple machines found in the classroom, being able to germinate seeds or using different models of the solar system for students of different ages and abilities

SCIENCE TEACHERS

The understanding of the important ideas, tools of inquiry and structure of science described above are appropriate for all teachers -- those who teach science as one of many school subjects and those who primarily teach science classes. However, because of the needs of older, more experienced students, science teachers, those who teach science courses at middle and high school, have understanding and ability of science beyond that of teachers of science who teach many school subjects. Again, the *National Science Education Standards* provide insight about the nature of this understanding and ability. In the Chapter on Professional Development, the Standards states that "One of the most serious questions in science education is what a science teacher needs to know. What does it mean to know a lot or a little, have a sound foundation, and have in-depth understanding? The criteria of credit hours that states, professional organizations, and higher education institutions use to prescribe content requirements are inadequate indicators of what is learned in a course. Therefore, the following discussion focuses on the nature of opportunities to learn science needed by teachers, rather than on credit hours (p. 59)." Later in the same section there is a statement that the understanding of science teachers "implies being familiar enough with a science discipline to take part in research activities within that discipline...An important test of the appropriate level of understanding for all teachers of science at all levels is the teacher's ability to determine what students understand about science and use this data to formulate activities that aid the development of sound scientific ideas by students (p. 60)."

In this section we describe what science teachers, those who teach science courses, are expected to understand and be able to do as they teach science. Following the suggestion of the *National Science Education Standards*, a single course or set of courses does not identify these understandings and abilities.

Inquiry

Because inquiry is essential to understanding science and because the nature of inquiry cannot be captured without experience, we believe that all science teachers must have an opportunity to engage in extended science inquiry in a laboratory or field setting. We believe that without such experiences the understanding of science as inquiry is inadequate. This immersion in science research is not equivalent to completing typical laboratory or field courses at an institution of higher education. This experience needs to include formulating and grappling with the statement of a question about natural phenomena, formulating appropriate hypotheses, designing appropriate data gathering techniques including making solutions or constructing equipment, discussing the outcomes of data and gathering with peers in a public forum to engage in discussions about the implications of the data for enhancing scientific theories and models. These opportunities to engage in scientific inquiry might occur in capstone courses at a university or might be associated with internships in businesses and industries that do science research.

Subject matter

Science teachers have subject matter understandings and abilities that include all those of teachers of science but also go beyond those understandings. As above, we provide representative examples. These examples are organized by the subject matter categories of the *National Science Education Standards* -- physical science, life science and Earth and space science. One of many possible examples is provided for each of the important science ideas in that category (See pages 9, 10 & 11 to review the entire list.) Then, for each category, one of numerous possible extended examples is provided.

In physical science, a teacher teaching

- atomic structure, would understand about the nature, discovery and utility of the subatomic particles.
- structure and properties of matter would understand about the different types of bonds and why different bonding structures are formed for different compounds.
- chemical reactions will have great facility with stoichiometry.
- motions and forces would understand the mathematics that describes and models these forces.
- conservation of energy would be able to interpret and construct phase diagrams and quantify and equate mechanical, heat, light and sound energy.
- interaction of energy and matter would know the history of human understanding about essential elements.

The chemistry teacher at the upper grade levels has an understanding of chemical reactions beyond the idea that chemistry is about change. The chemistry teacher has a working familiarity not just with general energy transformations and states of the bonding electrons but with the quantification of heat of reaction, enthalpy, entropy of activation and nuclear and electron-spin resonance spectroscopy. Further, these ideas imply knowledge beyond the ability to do and interpret the calculations. These concepts are essential to imagining the changes that could be possible in chemical interactions. It is this ability to imagine the possible that is the hallmark of a practicing chemist. Chemists are very good at making molecules that are not produced in nature. They find ways to manipulate the atomic and molecular properties of substances to coax them to form original and novel combinations -- nylon and teflon, for example. The teacher of chemistry at the secondary level recognizes that chemical synthesis is very close to an art form. The chemist's palette is her many different simple molecular substrates and her brushes are a holistic understanding of chemical reactions. It is through the practice of this scientific art that the idea of change is expanded in ways the alchemist could only dream.

A life science teacher, teaching

- the cell would know the membrane biochemistry and be able to use that understanding to explain how is able the cell to recognize other cells as self or non-self.
- molecular basis of heredity would understand the mutability of DNA by environmental agents: that all cancer is genetic but not all cancer is hereditary.
- behavior of organism would understand and know examples to illustrate that more and more of behavior in humans is attributed to genetics rather than learned.
- biological evolution would understand that changes in DNA are often spontaneous and nonpurposeful and so evolution of organisms based on changes in DNA are not purposeful.
- the interdependence of organisms would understand that predation is a necessary process for the survival of species. For example, moose actually depend on the wolves for survival of their species.
- matter, energy, and organization in living systems would understand that not all life forms fit the traditional pattern of dependency. Archae, a newly identified life form, utilizes energy differently than eukaryotes and prokaryotes through chemosynthesis.

The biology teacher at the upper grade levels needs to have an understanding of the molecular basis of heredity beyond the idea that instructions for specifying characteristics of an organism are carried in DNA. The biology teacher knows the relationship between DNA, chromosome and gene and is able to relate the molecular basis of heredity to classical Mendelian genetics. The biology teacher has a working familiarity with the structure and function of DNA including the strengths and weaknesses of different types of molecular models in promoting understanding. The biology teacher is familiar with replication, translation, transcription and protein synthesis. The biology teacher is able to relate a history of how the understanding of DNA as the basis of heredity has grown exponentially during the past half century, the people involved and the role technology has had in that growth. The biology teacher is able to report on the uses of biotechnology in human gene therapy and in the production of food crops. The biology teacher is aware of the progress of the Human Genome Project and knows the latest information on mammalian cloning. The biology teacher has a repertoire of case studies appropriate for upper level school students that allows them to consider and discuss the ethics of the applications of biotechnology.

An Earth and space science teacher, teaching

- energy in the earth system would understand the strengths and weaknesses of the competing models to explain mantle convection.
- geochemical cycles would understand that felsic materials such as muscovite, quartz and biotite crystallize at lower temperatures than mafic materials such as amphibole and olivine.
- origin and evolution of the earth system would be able to explain how to determine the geological history of an area from a roadcut and would be able to do so.
- origin and evolution of the universe would be able to explain that as the primitive universe cooled, protons and electrons formed helium nuclei and hydrogen and helium atoms.

The Earth science teacher at the upper levels has an understanding of global climate beyond the idea that it is determined by energy transfer from the sun at or near the Earth's surface. The Earth science teacher knows how energy is transferred through the atmosphere by radiation that is based on the temperature of an object. The Earth science teacher knows the solar constant, and why there is sufficient solar energy to make solar power feasible. The Earth science teacher understands that the dynamic processes such as cloud cover and rotation of the Earth and static processes such as the position of mountain ranges and oceans affect the temperature of the Earth. For example, the planet would be much colder if the continents were located at the poles and much warmer if the continents were at the equator. The Earth science teacher knows how global climate relates to local weather and can explain the principles of thermometers, barometers, hygrometers and psychrometer. The Earth science teacher is able to explain why weather forecasting remains an inexact science, even with technological improvements in forecasting.

Science in social and personal perspectives and the history of science

All science teachers have an understanding of the social and personal perspectives of science and the history and nature of science. Some teaching examples from these two categories of science content are included.

A science teacher, teaching

- personal and community health would understand how to construct a balanced diet and the symptoms of diet deficiencies both current (anorexia) and historical (scurvy).
- population growth would understand the influence of culture and custom on population growth and how these customs are influence by and influence resource availability as a population limit.
- natural resources would be able to identify many renewable and non-renewable resources and explain the relationship between natural resources and economy.
- environmental quality would be able to explain not only the factors that influence the environment but also how these factors influence one another.
- natural and human-induced hazards would be equally able to explain the causes and effects of hurricanes and soil erosion.
- science and technology would be able to complete a cost benefit analysis of a recent technological device and predict such an analysis for a proposed device.
- the nature of scientific knowledge would be able to analyze the accuracy of reports of scientific phenomena in local newspapers.
- the history of science would be able to explain the cycles of understanding common natural phenomena such as photosynthesis and how social and technological forces of a period in time influenced which ideas were ripe for exploration and which were overlooked.

The science teacher at the upper grade levels has an understanding of the nature, history and role of science that is beyond inquiry, concepts, models and theories. The science teacher understands that science is both dynamic and stable, that the power of an idea in science rests in its ability to explain and predict natural phenomena and that some ideas have been useful in explaining and predicting for a very long time while others have been of short duration. The science teacher understands that men and women with diverse interests and talents engage in scientific inquiry and that achievements of science are collaborative and cumulative. Scientists work together and build on the work of others, both predecessors and contemporaries and that for every person in science who has achieved fame, there are many other anonymous individuals who have made equally valuable contributions. The science teacher knows that society plays a role in determining what happens in science by providing an impetus to examine certain questions. The teacher also knows that society is affected by what happens in the world of science. The science teacher sees the place of science in all ordinary activities from personal decisions about what to eat to political decisions about modes of waste disposal. The science teacher sees scientific literacy as a goal for all as it provides a way to look at and live in the natural world.

Conclusion

Principle 1 of the INTASC Science Standards focuses on the teacher's understanding and abilities in a discipline, in this case science. This is expected, as teachers teach something to students. The understanding of the science is much more than the memorizing definitions of terms, completing routine investigations and astonishing students with esoteric facts. Principle 1 is quite clear that "the teacher of science understands the central concepts, tools of inquiry, applications, structures of science and of the science disciplines (physics, chemistry, biology and Earth and space science) he or she teaches." Numerous books have been written to describe what the nature of science is, what the central concepts of science are, exactly what it is that a scientist does and thinks as she goes about her work, and how the concepts and tools of science are applied in new situations. In this section we present an admittedly brief overview of what the science knowledge of a teacher might look like.

Principle 1 of the INTASC Science Standards further requires that teachers of science "can create learning experiences that make these aspects of content meaningful to students." Teachers of science must not only have a rich understanding of science, they must also imagine the science understanding and misunderstanding of their students and be able to design links between the two. The goal of all students attaining understanding science requires teachers who also understand science.

The remaining nine principles complement Principle 1 in describing the knowledge, skills and dispositions of a beginning professional teacher of science.

Principle 2: STUDENT LEARNING AND DEVELOPMENT

The teacher of science understands how students learn and develop and can provide learning opportunities that support their intellectual, social, and personal development.

Teachers of science understand how students learn; they also understand how students develop personally, intellectually, psychologically, physically, emotionally and socially. In addition, teachers of science understand science. The understanding of students and of science shape the science instruction in the classroom.

⇐ **See Principle 1**
Understanding Science Content

Teachers of science are knowledgeable and effective consumers of educational research about student learning and about student development. They have generated both a theory of learning and a theory of development, which inform their planning and instruction.

⇐ **See Principle 9**
Professional Development

Current research on learning points to the importance of students being actively engaged in constructing understanding of important science content. When designing and adapting instructional activities, teachers recognize that being engaged in hands-on activities by themselves may not be sufficient or even necessary for student understanding. As they participate in all science activities, students need to reason and reflect about what they are doing to achieve understanding of science content.

⇐ **See Principle 4**
Uses a Variety of Instructional Activities

Teachers of science realize that observation of natural phenomena is essential to learning science. However, observation ought to be followed by the organization of the observations and the generation of explanations and predictions. These, in turn, need to be followed by the formation of scientific principles, theories and models. Finally, these models are applied to new situations. Teachers of science also realize that involvement with observable natural phenomena comes before studying abstract terminology and conceptual schemes.

> Using the principles from an Aviation and Rocketry Unit, middle grades students might build and launch pop-bottle rockets, analyze the flight pattern and redesign the rocket.

Researchers also indicate that students bring a wealth of prior knowledge and experience to their science learning. Teachers of science adapt instructional activities to provide students opportunities to examine their current understanding as they create new understanding. In designing instruction, teachers of science know the misconceptions that are commonly held by students of the age they teach. They also know how to detect these misconceptions. Unless these misconceptions are consciously considered as students learn science, students are likely to return to their prior notions after instruction.

⇐ **See Principle 7**
Use Student Experiences when Planning

Teachers of science recognize that learning science is both an individual and a social process that requires personal reflection on and communication with others about science content. Teachers provide opportunities for students to do both. They also provide opportunities for students to develop the intra- and inter-personal skills needed for reflection and communication.

⇐ **See Principle 6**
Prepare Students for Discourse

Teachers of science use and adapt instructional activities as well as assessment tasks that focus on important science content, that are developmentally appropriate and meaningful to students. Such tasks both suit and enhance the interests, developmental level, knowledge, skills and experiences of the students.

⇐ **See Principle 8**
Align Assessment and Instruction

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the *National Science Education Standards* that "Learning is an active process (p.20)." The text continues, "The term 'active process' implies physical and mental activities. Hands-on activities are not enough – students must also have minds-on experiences (p.20)."

Principle 3: STUDENT DIVERSITY

The teacher of science understands how students differ in their approaches to learning and creates instructional opportunities that are adapted to diverse learners.

Teachers of science understand that each student comes to class with a personal set of interests, abilities, dispositions, values, needs, experiences, and knowledge, all of which influence a student's approach to learning. Recognizing this individuality, the teacher of science aims to develop the classroom as a community of diverse learners. Diversity encompasses notions of culture, gender, experience, interest, and alternative points of view as well as notions of understanding and ability. In a diverse community of learners all members have roles and responsibilities and everyone is respected. This respect is demonstrated by what teachers say and do as they plan, as they teach and as they respond to students and their interests, ideas, strengths, and needs.

Teachers of science understand that science offers a wide range of instructional activities to promote student understanding and ability. Science also provides opportunities for students to work alone, with a partner, with a group and with the whole class. Rich scientific inquiries provide opportunities for students to pursue their own explanations for their observations through many different types of activities. Further, some inquiries require that different students engage in different aspects of the same inquiry and then share their findings. The variety of ways students may participate in science make it possible for students with different approaches to learning to have equal opportunities to attain both scientific understanding and ability. Teachers plan instructional activities that provide for each student to engage in multiple types of activities and for different students to engage in different types of activities.

⇐ **See Principle 4**
Uses a Variety of Instructional Strategies

⇐ **See Principle 7**
Plan Instructional Activities

Teachers of science have an ever-growing repertoire of culturally and socially relevant examples, analogies and metaphors to enable them to support the science understanding of all students.

The frequently used owl pellet activity is in conflict with the cultural norms of some Native American Tribes.

Teachers of science know that in order to meet the learning needs of all students, they must be willing and able to adapt laboratory and field-based activities to provide a safe and equitable learning experience for all students including those with special needs -- physical, cognitive, psychological and social.

⇐ **See Principle 5**
Creates a Safe Learning Environment

Teachers of science select instructional activities and assessment tasks that have multiple solution paths and multiple solutions. Such activities and tasks allow students to display their strengths as they develop deep understanding of important science ideas, the abilities of scientific inquiry and the skills of application.

Teachers of science are aware of resources that can help them meet the needs of and incorporate the contributions of each student as all students come to understand science.

⇐ **See Principle 9**
Professional Development

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the Introduction to the *National Science Education Standards*. “Actions of teachers are deeply influenced by their understanding of and relationship with students. . . These relationships are grounded in knowledge and awareness of similarities and differences in students’ backgrounds, experiences and current views of science (p.29).”

Principle 4: INSTRUCTIONAL VARIETY

The teacher of science understands and uses a variety of instructional strategies to encourage students' development of critical thinking, problem solving, and performance skills.

Teachers of science understand that the nature of science, an understanding of how students learn and develop as well as the diversity of experience and ability that students bring to the classroom drive the planning of science instruction that focuses on understanding and inquiry. Teachers of science realize that understanding science ideas and scientific inquiry are mutually interdependent. Inquiry relies on and leads to understanding ideas and understanding ideas relies on and leads to inquiry. To engage fully in inquiry, students need to develop not only a rich body of ideas and reasoning abilities but also manipulative skills and communication abilities. Science ideas and inquiry both support the application of science to new issues.

⇐ **See Principle 2**
Understands How Students Learn

⇐ **See Principle 1**
Understands Science Content

Multiple modes of instruction are called for in order to nurture the natural curiosity of students about natural events. Science requires students collect, organize and recall information, design and conduct investigations, examine assumptions, make inferences, make generalizations, present structured arguments, and apply new information to existing natural and technological phenomena.

> High school students frequently confuse speed and velocity. To address the confusion have students walk across the classroom at different speeds and then create motion graphs.

Understanding science demands critical thinking, for example comparing two models of the same phenomena to determine which has the greater ability to explain and predict. Scientific inquiry includes problem solving, from being able to ask questions about natural events to being able to disconfirm alternate solutions to a problem. Science demands performance skills, such as being able to present a logical and persuasive argument from empirical evidence.

Learning science offers opportunities for students to read, write, discuss, draw, and make diagrams, charts and models. Students might access the Web for information, for data gathered by others or for communication with scientists and students in distant places. Computer technology enables students to run mathematical models, to complete data-producing strategic simulations, to draw animation to help explain dynamic concepts, and to prepare professional looking presentations to display data and inferences. Students might use video to observe natural phenomena that are too distant, too dangerous or occur too slowly to observe directly.

⇐ **See Principle 6**
Uses Multiple Forms of Discourse

Teachers of science know that whether reading a text, studying a research article, designing an investigation, organizing data on a computer, defending an idea or presenting conclusions during an exhibition, students can focus on both understanding, inquiry and application. Teachers also recognize that laboratory and field-based activities, especially around complex natural phenomena, are critical to science instruction.

⇐ **See Principle 5**
Creates a Safe Classroom Environment

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the Introduction to the *National Science Education Standards*. "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas (p.23)."

Principle 5: LEARNING ENVIRONMENT

The teacher of science uses an understanding of individual and group motivation and behavior to create a learning environment that encourages positive social interaction, active engagement in learning, and self-motivation.

Teachers of science maintain a learning environment that fosters the development of science understanding, inquiry and application for all students and a desire to continue as life-long learners of science. This learning environment includes both the psychosocial learning environment and the physical learning environment.

⇐ **See Principle 1**
Understands Science Content

Teachers of science understand that science is collaborative and therefore learning science frequently occurs in collaborative groups. When students are engaged in an inquiry that is of interest to them, members of the collaborative group rely on one another to ask and answer challenging questions. Based on the recognition that different members of a collaborative group bring different experiences and strengths, such group work encourages both personal responsibility and interdependence When using a collaborative group structure, teachers of science know how to initiate and encourage the group so that students work productively.

⇐ **See Principle 3**
Understands Student Diversity

Assigning students roles in an investigation is one way to support collaboration. Typical roles include principal investigator, recorder, and materials manager.

Whether students are working alone, in groups or as a class, teachers of science create an environment of mutual respect. In this environment, students know it is safe to take intellectual risks as they pose questions, propose predictions, make presentations and engage with others in explaining, clarifying, justifying and apply what they have learned.

Teachers of science recognize that organized planning and placement of materials and information is necessary to permit active engagement of students in safe and productive learning. Teachers ensure that there is adequate time for students to complete their inquiries and that the materials and equipment are appropriate, adequate and safe. The science learning environment must be physically safe but sufficiently unrestricted to allow for the display and manipulation of both work in progress and finished work. Teachers of science establish and enforce routines and rules for safe and effective activity in classrooms.

⇐ **See Principle 7**
Planning and Organization

Elementary school classrooms that lack a laboratory might group desks to make a table-like formation.

The classroom itself promotes science learning by the display of living organisms and non-living natural artifacts as well as appropriate print and media materials. Teachers of science know and observe the regulations and policies for the safe and ethical treatment of living organisms, science specimens and scientific data.

Maintaining a physical environment that supports science learning also requires that teachers of science gather, store, manipulate, and dispose of equipment and materials ranging from everyday household items to science-specific apparatus that are provided for by the school or district science budget.

Often the science learning environment transcends the traditional four walls of the classroom. Field experiences and visits to community resources must be well planned to ensure that they contribute to student science learning. The community also can enter the classroom through presentations by visitors who engage in scientific inquiry and have scientific understanding. In addition to, but not as a substitute for field experiences, students can have access to the entire world through appropriately regulated computer technology.

⇐ **See Principle 10**
Relationships within the Local Community

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the Teaching Standards of the *National Science Education Standards*. "Teachers of science design and manage learning environments that provide students with time, space and resources needed for learning science (p.43)."

Principle 6: COMMUNICATION

The teacher of science uses knowledge of effective verbal, nonverbal and media communication techniques to foster active inquiry, collaboration, and supportive interaction in the classroom.

Teachers of science, in support of science understanding, inquiry and application engage students in multiple forms of discourse. They provide adequate opportunities for students to communicate with one another orally, in writing, through symbols, models, charts and diagrams about appropriate, challenging and interesting science content. Teachers realize that being able to share one's own understanding with others is a necessary component of understanding. They recognize that students must master both forms of and skill in accurate data gathering, organization, interpretation and presentation.

An important aspect of science is the oral and written discourse that focuses the attention of students on how they know what they know and how their understanding connects to ideas in science, in other subjects, and the world beyond the classroom. Teachers directly support and guide this discourse in at least three ways. They require students to record their work, teaching the necessary skills such as the use of models, concept maps, diagrams, graphs, tables and charts. They also promote using many different forms of communication when and where appropriate such as spoken, written, pictorial, graphic, mathematical and electronic. Finally, they foster student reflection about how a task was done, why the task was done and how they as individuals developed a personal understanding of the scientific ideas.

The teacher knows there are multiple representations for the structure of a compound – symbolic, electron dot, ball-and-stick, and cloud, - and knows which will be most useful for supporting student understanding of the concept being considered

Teachers of science appreciate the particular importance of precision and accuracy of language and of mathematics in science. They know that some words have different or more precise meanings in science than they do in common usage. In addition, teachers of science are aware that some words have different meanings in different cultures. Understanding in science extends beyond words to meanings. Therefore, teachers of science introduce the technical scientific terminology and mathematical formulae when they anticipate that the terms and formulae will be meaningful to and understood by students. They use terms that are appropriate to the age of the students they are teaching and usually after students have had experience with the phenomena. They also are able to detect when students are using the words and equations without understanding.

⇐ **See Principle 1**
Understands Science Content

⇐ **See Principle 2**
Understands Student Learning

Teachers of science know how to ask different types of questions to elicit different kinds of student understanding.

⇐ **See Principle 4**
Uses a Variety of Instructional Strategies

Divergent questions or questions that require explanation and prediction rather than recall help students view science as inquiry. Teachers know instructional techniques that encourage student reasoning, such as waiting long enough when seeking answers to questions that require students to process ideas.

Teachers of science realize the need to be able to give and follow directions, especially in laboratory and fieldwork. Further, they model the communication, argumentation, and reliance on evidence they expect students to use and develop. In addition, teachers know how to use physical, mathematical and conceptual models to enhance communication, interaction and understanding in the science classroom.

Teachers of science know that their own use of nonverbal clues can promote or hinder student participation and understanding in science. They therefore monitor their own use of facial expressions, gesture, posture, distance and stance in the classroom as carefully as they monitor the words they use and the tone of their voice.

⇐ **See Principle 9**
Reflects on Practice

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the Teaching Standards of the *National Science Education Standards*. "Teachers of science guide and facilitate learning. In doing this they . . . orchestrate discourse among students about scientific ideas (p.32)."

Principle 7: CURRICULUM DECISIONS

The teacher of science plans instruction based upon knowledge of subject matter, students, the community, and curriculum goals.

Teachers of science have a deep understanding of science content in order to plan appropriate learning activities for students. They recognize science is an integrated balance of ideas, inquiry and application. Students must be provided with opportunities to experience each of these aspects of science as well as their synthesis. They understand that developing understanding through inquiry for application to new problems requires extensive time and experience; they therefore focus on important and meaningful science content when they plan.

⇐ **See Principle 1**
Understands Science Content

Teachers of science recognize that science and technology are parallel and complementary disciplines. While science addresses natural phenomena, technology addresses human phenomena. Scientific inquiry and technological problem solving have many similar features. Science informs technology while technology supports science.

The topic of genetic engineering provides multiple opportunities to include both science and technology.

Teachers of science rely on national documents such as the *National Science Education Standards* and the publications of Project 2061 as well as state and local curriculum documents to select appropriate and important science content and curriculum materials. They recognize that professionally prepared curriculum materials provide useful information and insights for their planning and instruction. As members of a school community, teachers of science are aware of the intended overall goals of the school curriculum and how the school goals are being met through the goals of the science program.

⇐ **See Principle 9**
Lifelong Learner

When planning, teachers of science listen and respond to student interests. They also lead students to new science ideas about which students didn't even know they had an interest. Teachers of science know that science happens all the time and in many places. They are aware of current topics that are holding students' interest, can relate these topics to science and incorporate them into instruction. Teachers of science also use their knowledge of how students learn and what is developmentally appropriate as they plan lessons.

⇐ **See Principle 3**
Understands Student Diversity

When planning science instruction, teachers are aware of the issues and needs of the community and the place of the community in the world. To provide information and materials for instruction, they make use of community resources such as scientists and others that rely on science as well as public and commercial facilities. They encourage visits to zoos, parks, museums and science centers. They also plan activities that encourage students to look for science in their everyday lives. Recognizing that students come to science class with a range of

⇐ **See Principle 10**
Membership in the Local Community

experiences, interests and understandings, teachers of science provide multiple ways to enable students to engage in and come to understand science. Teachers of science plan instruction that is sensitive to student values and adapts lessons to accommodate cultural conflicts.

Planning for science includes both long-range plans across the academic year as well as more immediate plans for units and individual lessons. Planning requires thinking about what students are to learn across the entire course, with each lesson and from lesson to lesson. Planning includes selecting learning goals and choosing the activities and materials that will promote these learning outcomes. Planning also includes careful consideration of how their mastery of the goals will be demonstrated and measured. Then teachers consider how their own actions will facilitate students attaining understanding.

⇐ **See Principle 2**
Understands How Students Learn

⇐ **See Principle 4**
Uses a Variety of Instructional Activities

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the Teaching Standards of the *National Science Education Standards*. “Teachers of science plan inquiry-based science programs for their students (p.30).”

Principle 8: ASSESSMENT

The teacher of science understands and uses formal and informal assessment strategies to evaluate and ensure the continuous intellectual, social and physical development of the student.

Attaining understanding and ability of science content encompasses a rich variety of outcomes: understanding important ideas, understanding and doing inquiry, and application of understanding and inquiry. Teachers of science gather information on all three aspects of science content. They know what counts as evidence of attainment of these outcomes and how to gather that evidence. Both in planning and during instruction, teachers of science prepare and implement an assessment program which blends a variety of these outcomes with a variety of modes of assessment to create a picture of the extent and organization of a student's understanding and ability. To create this picture, teachers use multiple forms of assessment such as research papers, portfolios, and performance tasks as well as more traditional forms of assessment such as multiple choice tests, essay answers and laboratory reports. This array of assessments allows students opportunities to demonstrate their attainments. With all types of assessment teachers consider student's special needs including physical disabilities, learning disabilities and limited English proficiency.

⇐ **See Principle 1**
Understands Science Content

⇐ **See Principle 3**
Understands Student Diversity

Teachers recognize there are multiple purposes for assessment including monitoring student progress, improving instruction, and reporting to concerned adults such as parents and administrators. They realize the value of less formal modes of assessment such as observation and conversation for improving student learning. Aware of demands for accountability, teachers of science also are obligated to provide opportunities that assure the students will be able to be successful on external, state- or nationally-mandated tests.

⇐ **See Principle 10**
Relationships with the Community

Teachers recognize that assessment, the data gathering process, provides the information necessary for evaluation and reporting. They have developed defendable rubrics and scoring systems to make valid and reliable inferences for evaluation purposes from the assessment data they gather. They also recognize that grades are only one of many ways, such as conferences, conversations, profiles, portfolios and performances, to report to students' parents and others about student attainments.

Analyzing the trash produced in the school on any given day provides opportunities to collect and analyze data.

In choosing ways to assess student understanding, teachers consider how continuous and on-going assessment support instruction and enhance student learning. When students complete an assessment task they also should learn from it. Assessment and instruction are designed simultaneously so that the goals of both, which is student learning, are congruent. Teachers recognize that the goal of improved student learning is met when they provide timely feedback to students about their achievement on instructional and assessment tasks.

Teachers of science value the use of self-assessment as an important component of a science program. Forms of self-assessment help teachers and students reflect on their personal accomplishments in science teaching and learning. Teachers understand that self-assessment not only helps students learn to be reflective but that it also brings important information to the teachers' understanding of students' science achievement.

⇐ **See Principle 6**
Discourse and reflection

Assessment means more than gathering information about students. Teachers of science also gather information on the opportunities students have had to achieve understanding. These assessments focus on the quality of instruction provided and the resources and supported provided to the science program by the school, the district and the community.

⇐ **See Principle 7**
Planning and Using Instructional Materials

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the Introduction to the *National Science Education Standards*. "The word 'assessment' is commonly equated with testing, grading and providing feedback to students and parents. However, these are only some of the uses of assessment data. Assessment of students and of teaching – formal and informal – provides teachers with the data they need to make the many decisions that are required to plan and conduct teaching (p.38)."

Principle 9: REFLECTIVE PRACTITIONERS

The teacher of science is a reflective practitioner who continually evaluates the effects of his/her choices and actions on others (students, parents, and other professionals in the learning community) and who actively seeks out opportunities to grow professionally.

Teachers of science reflect on their teaching and its effects on student learning by monitoring and evaluating their practice and the principles that inform that practice. They gather information about the effects of their teaching from formal sources such as student grades and school improvement plans and from informal sources such conversations with students, parents, teachers and scientists. Self-reflection provides a mechanism for teachers to gauge their continued development and application in all aspects of their professional life including knowledge of science content, students, pedagogy, learning and assessment. They employ a variety of self-reflection tools and techniques including observations, portfolios, journals, audio and videotapes and study groups. They understand the strengths and limitations of each of these tools. They use these tools for both descriptive and analytical reflection. They incorporate this reflection with research and study of education principles and of best practice to improve their own teaching.

In conjunction with a school professional development program, teachers of science develop a personal professional development plan based on research on teacher professional development, on best practice and on their own needs. In designing their personal plans, teachers identify and use local, district and national resources for professional development. This plan might rely on professional literature in both science and education; networks with people concerned with science and education; use of communication technology and media; internal and external opportunities for professional development such as workshops, conferences and courses; or regular discussion and study groups with peers. Teachers of science conduct classroom-based research to better understand the effect of their teaching on students' learning. They also understand the value of peer coaching and mentoring.

Teachers of science relate and connect scientific and pedagogical theory and practice. They study pedagogy to remain current in learning theory, instructional strategy, assessment technology and curriculum design and materials, for example. They may attend workshops, join school committees, field test new materials or work on local or national curriculum or assessment development projects. They study science to increase the breadth and depth of their understanding and to remain current with science content. They may attend classes, affiliate with a university or industry laboratory for a period or engage in less

⇐ **See Principle 2**
Understands How Students Learn

⇐ **See Principle 1**
Understands Science Content

formal activities such as watching science television shows and reading journals and books. Understanding science through inquiry is built over time through educational opportunities connected to, and in the context of, experiences both within the classroom and in collaboration with the community at large, including parents, scientists, business persons and others.

⇐ **See Principle 10**
Community Relationships

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the Professional Development Standards of the *National Science Education Standards*. "Professional development for teachers of science requires building understanding and ability for lifelong learning (p.68)."

Principle 10: COMMUNITY MEMBERSHIP

The teacher of science fosters relationships with school colleagues, parents, and agencies in the larger community to support students' learning and well being.

Teachers of science are members of the school community. As such they work with other teachers, administrators, staff and volunteers in the school to build for themselves a school community in which they discuss issues of teaching and learning. From these discussions they plan and implement programs that improve teaching and learning. Teachers also contribute to the well being of the school community by participating in school activities. They keep their administrators well-informed so administrators can fulfill their responsibilities in ensuring quality conditions for professional teachers such as adequate supplies and equipment, budget, time for collaboration and reflection, and opportunities for professional growth.

A teacher might join a school committee to examine increased coordination across school subjects.

Teachers of science know and obey the state and local policies and regulations for the safety and welfare of students in a science classroom. These regulations include those for the safe use, maintenance, storage and disposal of living organisms, chemicals, and equipment. The science classroom has the necessary safety equipment.

⇐ **See Principle 5**
Classroom Environment

Teachers of science are aware that their classroom community of learners is situated within the larger school community and that the school community in turn is part of the larger educational system. They work to keep all members of the school and local community involved and committed to scientific literacy for all students.

⇐ **See Principle 10**
Community Relationships

Teachers of science know the importance of assessment for accountability. They know that assessment data provides feedback to parents/guardians about their student's progress towards achieving curricular goals. Teachers know that school and/or district personnel and the community at large use the assessment data as feedback on the effectiveness of science curricula and programs. Teachers recognize that policy makers use this information to evaluate the effectiveness of current policy in promoting scientific literacy.

⇐ **See Principle 8**
Assessment

Teachers of science work with students, colleagues, parents, and other community members to provide opportunities that allow students to enhance their knowledge of science and utilize that knowledge within the community. They use local resources to complement and enhance student learning by connecting the community and the classroom. Science teachers comprehend the value of developing partnerships with local scientists and others for planning and implementing instruction. Recognizing that home life greatly influences student learning, teachers of science value consulting with parents or guardians

A sports event might provide the context for lessons on speed and velocity.

about the needs, abilities, and interests of individual students. Teachers of science advise parents of ways they can help students see science as an essential part of life outside of school.

Teachers of science recognize that being a professional requires being involved in professional activities beyond the classroom and school. They keep abreast of opportunities for professional activities so they can carefully select to engage in those that enhance their understanding and ability as a teacher of science.

A teacher might become active in the National Science Teachers Association

To illustrate consistency between INTASC and other current science education reform efforts, we quote from the Introduction to the *National Science Education Standards*. "Teachers are central to education, but they must not be placed in the position of being solely responsible for reform. Teachers will need to work within a collegial, organizational, and policy context that is supportive of good science teaching (p.27)."

Stories of Science Teaching

Teaching science to elementary school students: Evaporation in the Garden Center

The fourth grade teachers, along with the prospective teachers doing their field experience, have planned an eight week unit exploring changes of states of matter. The school's principal has structured the school day to allow the teachers at each grade to meet at common planning times three times per week. This has allowed the teachers and prospective teachers the opportunity to spend time together to discuss their teaching and learning as they transform pedagogical theory into classroom practice. During one of the planning sessions the decision was made that one target for this unit would be that the students develop increased ability to conduct scientific inquiry. Students would develop knowledge and understanding about changes of states of matter as well as an understanding of how scientists study the natural world.

⇐ **See Principle 9**
Plan in a Community of Teachers

⇐ **See Principle 1**
Understands Science Content

The teachers knew that it was critical to select instructional materials that linked content, teaching, learning, and assessment. One of the teachers had had the opportunity to serve on a curriculum selection committee at the district level. On this committee she learned the criteria used to determine exemplary curriculum materials. One of those criteria was that there should be evidence in the material of the use of some learning theory. The unit that the teachers chose to use was built on a four-part learning cycle model. These teachers have carefully and thoughtfully selected curriculum that uses this cycle not only in each lesson, but in the unit as a whole.

⇐ **See Principle 10**
Relationships in the District Community

⇐ **See Principle 8**
Plan Based on Knowledge of Student Learning

- **Getting Started**, where students discuss and share their knowledge while the teacher probes and assesses for prior and current understanding about the science content.
- **Exploring and Discovering**, where students work directly with science materials while the teacher observes, mediates, and facilitates student discussions in small groups and at the same time gathers information about student learning.
- **Processing for Meaning,** where students share their observations and compare data with each other and the whole class, while the teacher guides students in organizing their thinking and at the same time assesses students both formally and informally.
- **Extending Ideas,** where students connect their learning to other curricular areas and to real-life situations while the teacher provides opportunities for applications of student learning that demonstrate student understanding.

During the exploration of changes of state, the students were just finishing a series of activities related to evaporation. The students had formed collaborative groups where they were assigned specific jobs that they were required to perform. The students knew they were responsible for the group learning about evaporation and for each student coming to understand the concept. There has been lively discussion among the students and teachers about what they have learned. On the class data-recording chart, they have been reviewing both written explanations and student drawings. Some students have suggested that they think that evaporation happens more quickly when it is hotter. Everyone is comparing and discussing their drawings. One student points out that her drawing shows an ice cube with an arrow drawn to a puddle with another arrow to an empty space. The students seem to understand that water seems to "disappear," but are unsure about where it goes.

⇐ **See Principle 3**
Understands Motivation

⇐ **See Principle 6**
Promotes Effective Discourse

When the teachers met to discuss and compare the activities and work that the students have been doing in each class, one of the prospective teachers noted that it would be important that the next lesson help the students explore what happened to the water when it "disappeared." Agreement was reached that the students should now work with aspects of the topic of condensation.

⇐ **See Principle 2**
Understands How Students Learn

The next lesson required the students to build models utilizing two-liter plastic bottles. The students followed a procedure to assemble the equipment to study condensation. Each team of students picked up a bottle from which the top third had been removed. After pouring several cups of hot water into the bottle, they tightly covered the top with plastic wrap and placed several small ice cubes on top of the plastic wrap. Soon, droplets of water appeared on the underside of the plastic wrap. The students seemed quite amazed! They asked where the water come from and wondered how they could explain this phenomenon. The teachers (practicing and prospective) had been circulating in the room and asking the students where they thought the droplets had come from. Some students thought that the melting ice cubes leaked through the plastic wrap. The prospective teacher asked the students how they could change the experiment to show whether or not the plastic was leaking. One student suggested that they could color the ice cubes. If the plastic were leaking then the water under the plastic would be colored.

⇐ **See Principle 4**
Uses a Variety of Instructional Strategies

⇐ **See Principle 6**
Uses Effective Non-Verbal Communication

⇐ **See Principle 3**
Understands Student Diversity

After examining the students' drawings and written explanations and by interviewing the students, the teachers feel that some of the students have gained a level of understanding about the concepts of evaporation and condensation, but others are having problems providing evidence and explanations. When the teachers met to discuss the lesson, they noticed that the students that had trouble understanding condensation were the same students that had difficulty with evaporation. They realize that for some students they may have moved into a new lesson when the students still needed more experiences with prior concepts. Knowing this, the teachers decided to develop additional explorations about evaporation with small groups of students who needed more experience in order to develop an understanding of the concept. This time would also provide an opportunity for interviews with small groups of students. The interviews could help the teachers develop a better understanding about what the students understood and were able to do.

⇐ **See Principle 6**
Uses Multiple Forms of Representation

⇐ **See Principle 8**
Uses Informal Modes of Assessment

As the students continued their explorations, the teachers kept notes of the students' discussions, drawings and explanations that occurred during individual interviews. Later, while discussing the notes with the other teachers, they noticed a pattern in the answers. Some students were making connections about heat and cold and how they relate to evaporation and condensation. Other students were not. Some students were relating the experience to real-life situations. One girl talked about how, when her father boils water on the stove to cook spaghetti, she sees water forming on the cupboard above the stove. Some students were aware that a change of state had occurred. Others were not. The teachers realized that each child seemed to have a different level of understanding of the concept of changes of state. They also understood that they would have to use different kinds of assessment tools to find out what the students understood. The teachers know the importance of using multiple forms of assessment to gauge the varying levels of understanding of the students in their classes. The use of observations and interviews, coupled with careful questioning, could be more useful in understanding what students know than more traditional forms of assessment. It also made the teachers realize that sometimes additional experiences were needed to help students develop a clearer understanding of a concept. In the past they used assessment to evaluate the students, but were now also using it inform their instruction.

⇐ **See Principle 3**
Understands Differences in Student Learning and Experience

⇐ **See Principle 8**
Uses Assessment to Ensure Continuous Development of the Learner

As the unit neared completion, the teachers began struggling with the notion that the ideas that the students learned should have some application to situations and contexts common in their everyday experiences. The teachers knew that students had learned a lot about evaporation, condensation, and changes of state, but were trying to think of a way that students could apply

⇐ **See Principle 1**
Understands Science Content

their new knowledge. One of the teachers had been assigned to the School Beautification Committee and had been at the garden center the previous evening in preparation for a field trip. The teacher had noticed something interesting about the two ways that peat moss was sold. Since the students were soon going to the garden center to select the materials for the school property, the teachers developed a group project that would require the students to apply their knowledge of evaporation.

⇐ **See Principle 10**
Situates Learning in the Local Community

Peat moss is sold in either sealed bags or in open bins. The students were told that regardless of how the peat moss is sold, it is priced the same per pound. The problem is for the students to determine which way would be the best buy and to explain their answers. After the field trip, the teachers were excited about how the students had solved the problem. As the students had weighed the two types of peat moss, they noticed that the same volume of bagged peat moss was heavier than the same volume of binned moss. Opening one of the bags, the students noticed that the bagged moss was moister than the binned variety. The students decided that the binned moss was drier because some of the water in the moss had evaporated, therefore making it lighter in weight. The students had directly linked their understanding of evaporation to the problem posed to them at the garden center. The teachers all agreed that a student that could demonstrate her understanding of a concept to a situation outside of the classroom provided another valuable piece in the assessment of that student's understanding.

⇐ **See Principle 4**
Uses a Variety of Instructional Strategies

The opportunity that the teachers had to reflect on their learning, discuss pedagogy, and explore issues of assessment during the unit had made their teaching more effective and had also given them a better understanding of how students learn. This opportunity proved valuable for both the pre-service and mentor teachers.

⇐ **See Principle 9**
Reflects on Practice

Teaching science to middle grades students: Model Building

Ms. Wolf had anticipated that the opportunity to go outside and gather data around the school property would generate enthusiasm among her middle grades students. She was sorely disappointed when the students reported that taking random samples of different quadrants and carefully counting the number and type of plants and animals had been boring. The students had asked repeatedly why anyone would do such a thing.

During the summer while attending a week-long institute on improving science instruction for middle grades students, with a special emphasis on the integration of science, mathematics, language arts and social studies, she shared her disappointment with colleagues from along the East Coast. She was both surprised and relieved to learn that other middle grades science teachers had had similar experiences with this ecology activity. During supper one evening, Ms. Wolf, who was from Florida, and Mr. Miller, from Connecticut, jointly outlined an instructional sequence that provided a purpose for the quadrant study. Mr. Miller's students would gather samples and data from around their school to send to Ms. Wolf's students with a challenge -- from studying the samples and data, could they infer what the Connecticut school grounds looked like.

⇐ **See Principle 9**
Seeks Opportunities to Grow Professionally

⇐ **See Principle 10**
Fosters Relationships with Colleagues

Early in fall, Mr. Miller's students agreed to the challenge and began making quadrants and collecting samples from their school grounds. They had a serious discussion about the need for random samples in science and about the ethics of adjusting data to influence the conclusions. Mr. Miller's students really wanted to give Ms. Wolf's students some help.

⇐ **See Principle 1**
Understands Science Content

Meanwhile, Ms. Wolf, knowing that models and modeling was a topic for seventh grade students in the district science framework introduced the idea to her students. They discussed what a model is and what it is for; they discussed different kinds of models for different purposes; they discussed the advantages of graphic models, physical models and mathematical models; they discussed the role of models in both explaining and predicting. They even discussed why people who show off clothing in magazines are called models and one student brought in her collection of model airplanes.

⇐ **See Principle 7**
Plans Based on Curriculum Goals

⇐ **See Principle 2**
Understands How Students Learn

When the box of samples arrived in Florida from Connecticut, with the challenge, Ms. Wolf's students were excited and skeptical. They got into their teams and began to discuss where to begin. After some discussion in teams, the entire class debated what they should do to get started at meeting the challenge. As a class they decided they needed to organize the mess of data. They decided that they needed a table to show

⇐ **See Principle 5**
Creates a Positive Learning Environment

which data came from which side of the school in Connecticut. Then they began counting and organizing as they made data tables of the types and frequency of plants, animals and detritus from each side of the school and the distance of the sample from the building.

⇐ **See Principle 6**
Uses Non-Verbal Communication to Support Learning

The data were displayed in large charts so that the students could see them when they returned to their teams. The discussions in the teams were lively. When one student would make an assertion -- like I think there is a parking lot on the East Side – another student would ask what the evidence was for such an assertion. After some discussion the team would agree that the lack of plant samples and the excess of trash could be evidence that this is a place where cars and school buses would wait for students after school. The absence of plants indicated a surface that did not support plant life. The trash indicated hungry students, eager to eat on the way home and leaving candy wrappers and sandwich bags behind.

After each team had had time for several days to work on a model of the Connecticut school, the teams shared their progress in model construction. They had all begun with the same data; they were surprised to find that no two proposed models were the same. As they discussed why the models were different, the students began to challenge one another's assumptions. For example, could they assume that all schools had places for buses just because they came to school by bus? Maybe the students in Connecticut walked to school. They also began to discuss how well each team had considered all the evidence, whether they had all considered all the evidence equally, and what they had done when they thought the evidence was contradictory.

⇐ **See Principle 4**
Uses a Variety of Instructional Strategies

After this class discussion, the students returned to their teams and prepared their final models. Some teams chose to build three-dimensional models while others chose two-dimensional drawings. The teams each chose a member to speak for the group as they prepared a report on the features of their model and the reasons they thought accounted for all the evidence. They invited the other middle-grades students and teachers to attend their presentations. They videotaped their presentations and sent the tape to the students in Connecticut. The students in Mr. Miller's class reciprocated by making a tape of their school and sending it to Ms. Wolf's class. The students in Ms Wolf's class were surprised that no one had an exact model but each of their models had some features of the Connecticut school. They had another class discussion on the relationship between models and evidence. Finally, Ms. Wolf had each student write an essay on the role of models in science. The students also began to discuss how they would collect samples from their school to send to the new friends in Connecticut.

⇐ **See Principle 3**
Understands Ways in which Students Differ

⇐ **See Principle 8**
Uses Formal and Informal Assessments

Teaching science to high school students: Yeastie Beasties

Mr. Berhens was planning a six-week activity that would increase student understanding of the processes of science and critical thinking skills. In addition, he planned to increase communication and social skills as the students worked on the central concepts of yeast metabolism and behavior. He wanted the students to use observation skills, integrate current knowledge, and develop new knowledge as they worked on a team research project. By referring to the district curriculum, he expected the students had some basic knowledge about science processes. He also was aware from conversation with his students that many of them had never done a full inquiry. A full inquiry includes students recognizing a scientific problem and taking the research all the way through to writing the research summary and reporting to peers. He was confident that the students had some background knowledge of yeast metabolism. The students at ages 14-18 knew that yeast was involved in baking bread and in producing alcohol.

⇐ **See Principle 4**
Encourages Critical Thinking

⇐ **See Principle 2**
Understands How Students Learn

Mr. Berhens planned to use the students' prior knowledge to get them to make observations about a flask of bubbling yeast-molasses solution. This was a way of getting them to use their observation skills and to ask scientific questions. Some of these questions could be used later as a basis for a research project that would be completed over the next several weeks.

⇐ **See Principle 1**
Understands Science Content

For the first day, he prepared a two-liter flask for a demonstration. The flask contained a 50% molasses-water solution with 5 grams of yeast added. The flask was placed near the center of the room where all students could see it, make observations, and write down questions that came to mind. Each student was to write 5 observations and 5 questions about the contents of the flask. There was to be no student talking during this time.

⇐ **See Principle 6**
Uses Effective Verbal and Non-Verbal Communication

After about 15 minutes of observing, Mr. Berhens asked the students, "What did you observe?" At first, no one responded, after a wait- time of a minute or so, Mr. Berhens gave some reassuring looks to some students that looked at him. Those students shared their observations with the class. Soon, nearly all the students had responded. Some of the observations that were listed on chart paper were:

- There are bubbles rising in the flask.
- The liquid is brown.
- The bubbles get larger as they rise.
- There are more bubbles along the top of the flask than at the bottom.
- There is a creamy-gray layer at the bottom of the flask.
- The flask feels warm.

⇐ **See Principle 1**
Understands Science Content

Some of the questions, also listed on paper, were:

- Are the bubbles CO_2?
- What substances are being formed in the brown liquid?
- Why do yeast cells give off gas?
- What food do the yeast cells use?
- How does their own waste affect their growth?
- Would environmental pollutants like salt affect their growth?
- What do yeast cells look like?

⇐ **See Principle 6**
Uses Effective Verbal and Non-Verbal Communication

Mr. Berhens complimented the students on their excellent observations and questions. More observations and questions were added to the lists as he and students discussed the flask and its contents. Mr. Berhens and the students talked about the differences between observation, inference, and assumption.

Next, Mr. Berhens focused on the questions about the flask. He drew on the collective knowledge of the class to answer some of them. Other questions were answered by the students from the textbook and other sources such as the World Wide Web. Some were answered through experimentation and more observation; for example, students made slides of yeast cells and looked at them through the microscope. One student demonstrated that a burning match would be extinguished by holding it over the open flask. The discussion, research and directed laboratory work continued until most of the questions had been answered.

⇐ **See Principle 3**
Understands Ways in which Students are Different from One Another

Mr. Berhens then asked students for other questions or comments that they might have about yeast. One girl indicated that she had a yeast throat infection. Mr. Berhens now wanted to focus on some of the questions that could not be answered by using textbooks, print and electronic media or confirmation laboratory work. For example, the students were unsure of how environmental pollutants would affect yeast growth. "What is the best amount and kind of food?" one student asked. The students were encouraged to ask more of those kinds of questions. Mr. Berhens listed various substances on the board that the students thought might influence yeast cell growth. About 100 substances were listed. Some of these were:

⇐ **See Principle 2**
Understands How Students Learn

- Excessive amounts of alcohol and CO_2
- Salt, used extensively on roads in winter
- Different kinds of sugars, mono, di, and polysaccharides
- Cranberry juice, which is advertised to reduce urinary tract infections in females.
- Fungicides, used to treat athlete's foot infections.
- X-rays, used medically.
- Ultra-sound, used medically.
- Antiseptics, Listerine, Lysol.

⇐ **See Principle 1**
Understands Science Content

- Garlic extract.

Mr. Berhens now organized the students into research teams consisting of four students each. Each team, after careful consideration, was instructed to choose a research variable. An outline was provided which listed the parts of the research that were to be completed by the students -- problem, hypothesis, literature search, experimental design, data collection, organization, interpretation, conclusion (summary), and considerations for further research. The teacher told the students that once they were finished with their research, they would present it to their peers and the instructor for analysis and evaluation. The report would be videotaped for further reference. An outline form for the evaluation was provided.

⇐ **See Principle 5** Understands Group Motivation

The students were confused as to what the final research report would look like. Mr. Berhens showed two videotapes of previous year's reports. The students referred to the evaluation outline as they watched the other teams present. This helped the students understand what was expected in the team presentations. It was helpful to know that both their classmates and the teachers would be asking them questions and evaluating their research.

⇐ **See Principle 8** Uses Authentic Assessments

Mr. Berhens stated that it was time for each team to choose a research variable. He asked each team to choose something that they were really interested in. Each team discussed possible variables for the rest of the class period. They were to ask parents and others in the community about possible topics that would influence yeast population growth. The next day the discussions continued until close to the end of the hour. The teacher then asked one member of each team to share the teams' research variable. The team's reported by names they had made-up for themselves: Yeastie Beasties, Ultrasound (which indicated the variable and also that a team member's mother was an ultrasound technician), The Bubblers, X-rays (again indicating the variable and that a team member's father was a dentist), Clueless, Mycelex (the variable was a fungicide), Anonymous (the team chose as a variable extra alcohol) and Juices (who considered cranberry juice extract as a variable).

⇐ **See Principle 10** Fosters Relationships with the Community

The students were encouraged to search for relevant background information and literature for each of their team's variables. They used the school library, community resources (bakery, brewery and a yeast expert at a local university), and the Internet for information. While on the Internet, they used Webcrawler, Yahoo, Excite and other search engines. One team got over 100,000 hits when they put in the word "yeast." Web sites were visited and the Merck Index was used to gain useful information.

The students were instructed to use the information gained from all sources to design their research projects. Data were collected, organized and interpreted. Computers were used to

⇐ **See Principle 1** Understands Science Content

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