
Becoming an effective science teacher is a continuous process that stretches across the life of a teacher, from his or her undergraduate years to the end of a professional career.

# Standards for Professional Development for Teachers of Science

The *National Science Education Standards* present a vision of learning and teaching science in which all students have the opportunity to become scientifically literate. In this vision, teachers of science are professionals responsible for their own professional development and for the maintenance of the teaching profession. The standards in this chapter provide criteria for making judgments about the quality of the professional development opportunities that teachers of science will need to implement the *National Science Education Standards*. ▮ Professional development for teachers should be analogous to professional development for other professionals. Becoming an effective science teacher is a continuous process that stretches from preservice experiences in undergraduate years to the end of a professional career. Science has a rapidly changing knowledge base and expanding relevance to societal issues, and teachers will need ongoing opportunities to build their understanding and ability. Teachers also must have opportunities to develop understanding of how students with diverse interests, abilities, and experiences make sense of scientific ideas and what a teacher does to support and guide all students. And teachers require the opportunity to study and engage in research on science teaching and learning, and to share with colleagues what they have learned.

The standards in this chapter are intended to inform everyone with a role in professional development. They are criteria for the science and education faculties of colleges and universities, who have the primary responsibility for the initial preparation of teachers of science; for teachers who select and design activities for personal professional development; and for all others who design and lead professional development activities.

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These standards are also criteria for state and national policy makers who determine important policies and practices, such as requirements for teacher certification and the budget for professional development. In this vision of science education, policies must change so that ongoing, effective professional development becomes central in teachers' lives.

The current reform effort in science education requires a substantive change in how science is taught. Implicit in this reform is an equally substantive change in professional development practices at all levels. Much current professional development involves traditional lectures to convey science content and emphasis on technical training about teaching. For example, undergraduate science courses typically communicate science as a body of facts and rules to be memorized, rather than a way of knowing about the natural world; even the science laboratories in most colleges fail to teach science as inquiry. Moreover, teacher-preparation courses and inservice activities in methods of teaching science frequently emphasize technical skills rather than decision making, theory, and reasoning. If reform is to be accomplished, professional development must include experiences that engage prospective and practicing teachers in active learning that builds their knowledge, understanding, and ability. The vision of science and how it is learned as described in the *Standards* will be nearly impossible to convey to students in schools if the teachers themselves have never experienced it. Simply put, preservice programs and professional development activities for practicing teachers must model good science teaching, as described in the teaching standards in Chapter 3.

Four assumptions about the nature of professional development experiences and about the context within which they take place frame the professional development standards:

- **Professional development for a teacher of science is a continuous, lifelong process.**

- **The traditional distinctions between "targets," "sources," and "supporters" of teacher development activities are artificial.**
- **The conventional view of professional development for teachers needs to shift from technical training for specific skills to opportunities for intellectual professional growth.**
- **The process of transforming schools requires that professional development opportunities be clearly and appropriately connected to teachers' work in the context of the school.**

See Professional Development Standard D

**PROFESSIONAL DEVELOPMENT FOR A TEACHER OF SCIENCE IS A CONTINUOUS, LIFELONG PROCESS.** The understanding and abilities required to be a masterful teacher of science are not static. Science content increases and changes, and a teacher's understanding in science must keep pace. Knowledge about the process of learning is also continually developing, requiring that teachers remain informed. Further, we live in an ever-changing society, which deeply influences events in schools; social changes affect students as they come to school and affect what they need to carry away with them. In addition, teachers must be involved in the development and refinement of new approaches to teaching, assessment, and curriculum.

See Professional Development Standard A

Teachers of science build skills gradually, starting in their undergraduate years, where they engage in science and gain some experience in teaching. They then experience the realities of their first years in the classroom, work with other teachers, take advantage of professional development offerings, and learn from their own efforts and those of their colleagues. This gradual development has several implications—the transition between the education of prospective and practicing teachers is a case in point. The primary responsibility for the early stages of preservice education rests with colleges and universities, but it must be shared with the practice community as prospective teachers begin their clinical work. For inservice education, the practice community has the major responsibility, drawing upon the resources of higher education, science-rich centers, and the scientific community. Continuous professional development requires a gradual shift from campus to school, accompanied by collaboration among all those engaged in professional development activities.

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Because the following standards assume continuous professional development, they are not divided into standards for the education of prospective teachers and standards for the professional development of practicing teachers. Rather they are applicable to all activities and programs that occur over a teacher's career.

**THE TRADITIONAL DISTINCTIONS BETWEEN "TARGETS," "SOURCES," AND "SUPPORTERS" OF TEACHER DEVELOPMENT ACTIVITIES ARE ARTIFICIAL.** In the vision of science education described by the *Standards*, practicing teachers—traditionally the targets for professional development—have the opportunity to become sources of their own growth as well as supporters of the growth of others. Prospective teachers must have the opportunity to become active participants in schools through internships, clinical studies,and research. Teachers should have opportunities for structured reflection on their teaching practice with colleagues, for collaborative curriculum planning, and for active participation in professional teaching and scientific networks. The challenge of professional development for teachers of science is to create optimal collaborative learning situations in which the best sources of expertise are linked with the experiences and current needs of the teachers.

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Principals and qualified community members should also participate in professional development activities in order to increase their own understanding of student science learning and of the roles and responsibilities of teachers.

**THE CONVENTIONAL VIEW OF PROFESSIONAL DEVELOPMENT FOR TEACHERS NEEDS TO SHIFT FROM TECHNICAL TRAINING FOR SPECIFIC SKILLS TO OPPORTUNITIES FOR INTELLECTUAL PROFESSIONAL GROWTH.** This assumption highlights the need for a shift from viewing teaching as a technical activity to one requiring both theoretical and practical understanding and ability. Professional development occurs in many more ways than delivery of information in the typical university course, institute, or teacher workshop. Another way to learn more about teaching science is to conduct classroom-based research, and a useful way to learn science content is to participate in research at a scientific laboratory. In all instances, professional development activities must be sustained, contextual,and require participation and reflection. The *Standards* assume broad concepts of how, in what formats,and under what conditions professional development can take place.

**THE PROCESS OF TRANSFORMING SCHOOLS REQUIRES THAT PROFESSIONAL DEVELOPMENT OPPORTUNITIES BE CLEARLY AND APPROPRIATELY CONNECTED TO TEACHERS' WORK IN THE CONTEXT OF THE SCHOOL.** Whenever possible, the professional development of teachers should occur in the contexts where the teachers' understandings and abilities will be used. Although learning science might take place in a science laboratory, learning to teach science needs to take place through interactions with practitioners in places where students are learning science, such as in classrooms and schools.

# The Standards

The first three professional development standards can be summarized as learning science, learning to teach science, and learning to learn.Each begins with a description of what is to be learned followed by a description of how the opportunities to learn are best designed. The fourth standard addresses the characteristics of quality professional development programs at all levels.

**PROFESSIONAL DEVELOPMENT STANDARD A:**

**Professional development for teachers of science requires learning essential science content through the perspectives and methods of inquiry. Science learning experiences for teachers must**

- **Involve teachers in actively investigating phenomena that can be studied scientifically, interpreting results, and making sense of findings consistent with currently accepted scientific understanding.**
- **Address issues, events, problems, or topics significant in science and of interest to participants.**
- **Introduce teachers to scientific literature, media,and technological resources that expand their science knowledge and their ability to access further knowledge.**
- **Build on the teacher's current science understanding, ability, and attitudes.**
- **Incorporate ongoing reflection on the process and outcomes of understanding science through inquiry.**
- **Encourage and support teachers in efforts to collaborate.**

## KNOWLEDGE AND UNDERSTANDING OF SCIENCE

One of the most serious questions in science education is what science a 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 the opportunities to learn science needed by teachers, rather than on credit hours. It is assumed that teachers of science will continue to learn science throughout their careers.

To meet the *Standards*, all teachers of science must have a strong, broad base of scientific knowledge extensive enough for them to

- Understand the nature of scientific inquiry, its central role in science, and how to use the skills and processes of scientific inquiry.
- Understand the fundamental facts and concepts in major science disciplines.
- Be able to make conceptual connections within and across science disciplines, as well as to mathematics, technology, and other school subjects.
- Use scientific understanding and ability when dealing with personal and societal issues.

**See Content Standards (all grade levels) in Chapter 6**

Beyond the firm foundation provided by the content standards in Chapter 6, how much more science a teacher needs to know for a given level of schooling is an issue of breadth versus depth to be debated and decided locally while respecting the intent of the *Standards*.

Breadth implies a focus on the basic ideas of science and is central to teaching science at all grade levels. Depth refers to knowing and understanding not only the basic ideas within a science discipline, but also some of the supporting experimental and theoretical knowledge. The ways ideas interconnect and build upon each other within and across content areas are other important aspects of the depth of understanding. The depth of understanding of science content required varies according to the grade level of teaching responsibility.

Teachers of grades K-4 usually are generalists who teach most, if not all, school subjects. A primary task for these teachers is to lay the experiential, conceptual, and attitudinal foundation for future learning in science by guiding students through a range of inquiry activities. To achieve this, elementary teachers of science need to have the opportunity to develop a broad knowledge of science content in addition to some in-depth experiences in at least one science subject. Such in-depth experiences will allow teachers to develop an understanding of inquiry and the structure and production of science knowledge. That knowledge prepares teachers to guide student inquiries, appraise current student understanding, and further students' understanding of scientific ideas. Although thorough science knowledge in many areas would enhance the work of an elementary teacher, it is more realistic to expect a generalist's knowledge.

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Science curricula are organized in many different ways in the middle grades. Science experiences go into greater depth, are more quantitative, require more sophisticated reasoning skills, and use more sophisticated apparatus and technology. These requirements of the science courses change the character of the conceptual background required of middle level teachers of science. While maintaining a breadth of science knowledge, they need to develop greater depth of understanding than their colleagues teaching grades K-4. An intensive, thorough study of at least one scientific discipline will help them meet the demands of their teaching and gain appreciation for how scientific knowledge is produced and how disciplines are structured.

At the secondary level, effective teachers of science possess broad knowledge of all disciplines and a deep understanding of the scientific disciplines they teach. This implies being familiar enough with a science discipline to take part in research activities within that discipline.

Teachers must possess the skills necessary to guide inquiries based on students' questions. 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 to use this data to formulate activities that aid the development of sound scientific ideas by their students.

## LEARNING SCIENCE

Prospective and practicing teachers of science acquire much of their formal science knowledge through coursework in colleges and universities. For all teachers, undergraduate science courses are a major factor in defining what science content is learned. Those courses also provide models for how science should be taught. For K-4 teachers

See System Standard B

and 5-8 teachers with general certification, undergraduate introductory science courses often are the only science courses taken. Because of the crucial role of such courses, reform in the content and teaching of undergraduate science is imperative. The courses for practicing teachers—those taught at universities as part of graduate programs as well as those typically included in school-based,inservice programs—also require redesign.

Teachers of science will be the representatives of the science community in their classrooms, and they form much of their image of science through the science courses that they take in college. If that image is to reflect the nature of science as presented in these standards, prospective and practicing teachers must take science courses in which they learn science through inquiry, having the same opportunities as their students will have to develop understanding. College science faculty therefore must design courses that are heavily based on investigations, where current and future teachers have direct contact with phenomena, gather and interpret data using appropriate technology, and are involved in groups working on real, open-ended problems. Those science courses must allow teachers to develop a deep understanding of accepted scientific ideas and the manner in which they were formulated. They must also address problems, issues, events, and topics that are important to science, the community, and teachers.

Learning science through inquiry should also provide opportunities for teachers to use scientific literature,media, and technology to broaden their knowledge beyond the scope of immediate inquiries. Courses in science should allow teachers to develop understanding of the logical reasoning that is demonstrated in research papers and how a specific piece of research adds to the accumulated knowledge of science. Those courses should also support teachers in using a variety of technological tools, such as computerized databases and specialized laboratory tools.

In the vision described by the *Standards*, all prospective and practicing teachers who

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study science participate in guided activities that help them make sense of the new content being learned, whether it comes by lecture, reading, small-group discussion, or laboratory investigation. Courses and other activities include ongoing opportunities for teachers to reflect on the process and the outcomes of their learning. Instructors help teachers understand the nature of learning science as they develop new concepts and skills. Those who teach science must be attentive to the scientific ideas that teachers bring with them, provide time for learning experiences to be shared, and be knowledgeable about strategies that promote and encourage reflection.

Science faculty also need to design courses for prospective and practicing teachers that purposely engage them in the collaborative aspects of scientific inquiry. Some aspects of inquiry are individual efforts, but many are not, and teachers need to experience the value and benefits of cooperative work as well as the struggles and tensions that it can produce.

**PROFESSIONAL DEVELOPMENT STANDARD B:**
**Professional development for teachers of science requires integrating knowledge of science, learning, pedagogy, and students; it also requires applying that knowledge to science teaching. Learning experiences for teachers of science must**

- **Connect and integrate all pertinent aspects of science and science education.**
- **Occur in a variety of places where effective science teaching can be illustrated and modeled, permitting teachers to struggle with real situations and expand their knowledge and skills in appropriate contexts.**
- **Address teachers' needs as learners and build on their current knowledge of science content, teaching, and learning.**
- **Use inquiry, reflection, interpretation of research, modeling, and guided practice to build understanding and skill in science teaching.**

## KNOWLEDGE OF SCIENCE TEACHING

Effective science teaching is more than knowing science content and some teaching strategies. Skilled teachers of science have special understandings and abilities that integrate their knowledge of science content, curriculum, learning, teaching, and students. Such knowledge allows teachers to tailor learning situations to the needs of individuals and groups. This special knowledge, called "pedagogical content knowledge," distinguishes the science knowledge of teachers from that of scientists. It is one element that defines a professional teacher of science.

In addition to solid knowledge of science, teachers of science must have a firm grounding in learning theory—understanding how learning occurs and is facilitated. Learning is an active process by which students individually and collaboratively achieve understanding. Effective teaching requires that teachers know what students of certain ages are likely to know, understand, and be able to do; what they will learn quickly; and what will be a struggle. Teachers of science need to anticipate typical misunderstandings and to

**See the principle *Learning science is an active process* in Chapter 2**

*Skilled teachers of science have special understandings and abilities that integrate their knowledge of science content, curriculum, learning, teaching, and students.*

judge the appropriateness of concepts for the developmental level of their students. In addition, teachers of science must develop understanding of how students with different backgrounds, experiences, motivations, learning styles, abilities, and interests learn science. Teachers use all of that knowledge to make effective decisions about learning objectives, teaching strategies, assessment tasks, and curriculum materials.

**See Teaching Standard B**

Effective teachers of science also have a broad repertoire of instructional strategies that engage students in multiple ways. They are familiar with a wide range of curricula. They have the ability to examine critically and select activities to use with their students to promote the understanding of science.

**See Program Standard B**

Inquiry into practice is essential for effective teaching. Teachers need continuous opportunities to do so. Through collaborations with colleagues, teachers should

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inquire into their own practice by posing questions such as the following:

*How should laboratory journals be structured?*

*Is this experiment appropriate for the understanding and ability of the students?*

*What type of research do students need to do to extend their understanding?*

*Is this curriculum unit appropriate for this group of third-grade students?*

*Does a particular study allow students sufficient opportunity to devise their own experiments?*

*Are all students participating equally?*

**See Teaching Standard C**

Assessment is an important tool for good inquiry into teaching. In the daily operation of their classrooms, skilled teachers of science are diagnosticians who understand students' ideas, beliefs, and reasoning. Effective teachers are knowledgeable about the various educational purposes for assessment and know how to implement and interpret a variety of assessment strategies.

**See Teaching Standards D and E**

Skilled teachers of science also know how to create and manage the physical, social, and intellectual environment in a classroom community of science learners.

## LEARNING TO TEACH SCIENCE

Developing pedagogical content knowledge of science requires that teachers of science have the opportunity to bring together the knowledge described above and develop an integrated view of what it means to teach and learn science. The teaching standards in Chapter 3 are designed to guide teachers' decisions about each of the complex activities involved in teaching science. In the vision described by the *Standards*, teachers also develop concepts and language to engage in discourse with their peers about content, curriculum, teaching, learning, assessment,and students.

The development of pedagogical content knowledge by teachers mirrors what we know about learning by students; it can be fully developed only through continuous experience. But experience is not sufficient. Teachers also must have opportunities to engage in analysis of the individual components of pedagogical content knowledge—science, learning, and pedagogy—and make connections between them.

**See Professional Development Standard D**

In this vision, people responsible for professional development work together with each other and with teachers as they integrate their knowledge and experiences. For example,higher education science and education faculty must learn to work together: An instructor in a university science course might invite a member of the science education faculty to participate in regular discussion time designed to help students reflect on how they came to learn science concepts. Not only must the departments in higher education institutions work together, but schools and higher education institutions must enter into true collaboration. And

# Genetics

*Ms. J. recently attended a workshop with other teachers at the university where she learned equally from the instructors and the other attendees. She also reads research regularly, reviews resources, and makes judgments about their value for her teaching. Ms. J. engages in an iterative planning process, moving from a broad semester plan to daily details. The students in her high-school class have opportunities to develop mental models, work with instructional technology, use multiple materials, teach one another, and consider the personal, social, and ethical aspects of science. She has the support of the school and district and has the resources she needs. She also relies on resources in the community.*

*[This example highlights some elements from Teaching Standards A, B, D, and E; Professional Development Standards A, B, and C; 9-12 Content Standards A, C, F, and G; Program Standards C and D; and System Standards D and G.]*

Ms. J. is eager to begin the school year, and is particularly looking forward to teaching a semester course on transmission genetics—how traits are inherited from one generation to the next. She taught the course before and read extensively about the difficulties students have with transmission genetics conceptually and as a means of developing problem-solving skills. She also has been learning about new approaches to teaching genetics. From her reading and from a workshop she attended for high-school teachers at the local university, she knows that many people have been experimenting with ways to improve genetics instruction. She also knows that several computer programs are available that simulate genetics events.

Ms. J. is convinced that many important learning goals of the schoolís science program can be met in this course. She wants to provide the students with opportunities to understand the basic principles of transmission genetics. She also wants them to appreciate how using a mental model is useful to understanding. She wants her students to engage in and learn the processes of inquiry as they develop their mental models. Ms. J. also wants students to understand the effect of transmission genetics on their lives and on society; here she wants them to address an issue that includes science and ethics.

Selecting an appropriate computer program is important, because simulation will be key to much of the first quarter of the course. Ms. J. has reviewed several and noted common features. Each simulation allows students to select parental phenotypes and make crosses. Offspring were produced quickly by all the programs; genotypes and phenotypes are distributed stochastically according to the inheritance pattern. With such programs, students will be able to simulate many generations of crosses in a single class period. All the programs are open-ended—no answer books are provided to check answers. All the programs allow students to begin with data and construct a model of the elements and processes of an inheritance pattern. Students will be able to use the model to predict the phenotypes and genotypes of future offspring and check predictions by making the crosses. Ms. J. chooses one of the simulations after reviewing it carefully and considering the budget she has for supplies. Enough computers are available to permit students to work in teams of four.

Students will work in their teams to develop models of inheritance patterns during the first quarter. Ms. J. plans to obtain reprints of Mendel's original article for students to read early in the quarter. It has a nice model for an inheritance pattern, and students will examine it as they identify elements of a mental model. In addition to using the simulations, Ms. J. wants students to work with living organisms. She will need to order the proper yeast strains, fruit flies, and Fast Plants. She has commercially prepared units in genetics using each of these organisms and has adapted the units to meet the needs of the students. Each organism has advantages and limitations when used to study transmission genetics; students will be working in teams and will share with other teams what they learn from the different organisms.

During the second quarter, students will focus on human genetics. Ms. J. intends to contact the local university to arrange for a particular speaker from the clinical genetics department. The speaker and Ms. J. have worked together before, and she knows how well the speaker presents information on classes of inherited human disorders, human pedigree analysis, new research in genetic susceptibility to common illnesses, and the many careers associated with human genetics. Someone from the state laboratory also will come and demonstrate

karyotyping and leave some photographs so students can try sorting chromosomes to get a feel for the skill required to do this. Having students perform a karyotype will give new meaning to a phrase in the text: "the chromosome images are sorted by type."

Each student will become an "expert" in one inherited human disorder, learning about the mode of inheritance, symptoms, frequency, effect on individuals and family, care, and such. Students will present their reports to the class. They will also work in pairs to solve an ethical case study associated with an inherited disorder. Drawing on several articles about teaching ethical issues to children, Ms. J. has created one of her own, and with the help of colleagues and the staff at the clinical genetics center, she has developed several case studies from which the students will develop their ethical issue papers. Part of the case study will require students to draw a pedigree. Ms. J. is gathering print matter: fliers from the March of Dimes, textbooks on clinical genetics, some novels and short stories about people with inherited disorders, and articles from popular magazines. This is an ongoing effort—she has been collecting material for some years now. She also has posters and pictures from service organizations she will put up around the room, but some wall space needs to be saved for student data charts.

Having reviewed the goals and structure of the course, Ms. J.'s next planning step is to map tasks by week. She has a good idea of how long different activities will take from her previous experience teaching this course. Planning for each week helps ensure that the live materials and the speakers are coordinated for the right time. But Ms. J. knows that it is likely that she will need to adjust scheduling. Ms. J. and the students will set routines and procedures during the first week; then students will do much of the class work in their teams.

Finally, Ms. J. begins to map out the days of the first week. On the first day of class, the students will share why they chose this course and what their hopes and expectations are. They might also describe what they already know about genetics and what questions they bring to class.

science-rich centers, industry, and other organizations must participate in professional development activities with teachers.

**See Program Standard D and System Standard D**

Some of the most powerful connections between science teaching and learning are made through thoughtful practice in field experiences, team teaching, collaborative research, or peer coaching. Field experience starts early in the preservice program and continues throughout a teaching career. Whenever possible, the context for learning to teach science should involve actual students, real student work, and outstanding curriculum materials. Trial and error in teaching situations, continual thoughtful reflection, interaction with peers, and much repetition of teaching science content combine to develop the kind of integrated understanding that characterizes expert teachers of science.

New forms of collaboration that foster integrated professional development for teachers must be developed. One promising possibility is the reorganization of teacher education institutions into a professional development school model, where practitioners and theoreticians are involved in teacher education activities in a collegial relationship. Another is extensive collaboration among schools, colleges, local industry, and other science-rich centers.

Many teachers come to learning activities with preconceptions about teaching science. At a minimum, their own science learning experiences have defined teaching for them. More accomplished teachers have their own teaching styles and strategies and their own views of learning and teaching. When teachers have the time and opportunity to describe their own views about learning and teaching, to conduct research on their own teaching, and to compare, contrast, and revise their views, they come to understand the nature of exemplary science teaching.

Learning experiences for prospective and practicing teachers must include inquiries into the questions and difficulties teachers have. Assessment is an example. Teachers must have opportunities to observe practitioners of good classroom assessment and to

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review critically assessment instruments and their use. They need to have structured opportunities in aligning curriculum and assessment, in selecting and developing appropriate assessment tasks, and in analyzing and interpreting the gathered information. Teachers also need to have opportunities to collaborate with other teachers to evaluate student work—developing, refining, and applying criteria for evaluation. Practicing teachers will benefit from opportunities to participate in organized sessions for scoring open-ended assessments.

**See *Assessments Conducted by Classroom Teachers* in Chapter 5**

Professional development activities create opportunities for teachers to confront new and different ways of thinking; to participate in demonstrations of new and different ways of acting; to discuss, examine, critique, explore, argue, and struggle with new ideas;

to try out new approaches in different situations and get feedback on the use of new ideas,skills, tools, and behaviors; to reflect on the experiments and experiences of teaching science, and then to revise and try again.

Teacher learning is analogous to student learning: Learning to teach science requires that the teacher articulate questions,pursue answers to those questions, interpret information gathered, propose applications, and fit the new learning into the larger picture of science teaching.

These suggestions for preservice and inservice professional development do not dictate a certain structure. They could be met in a college course, a sustained inservice workshop or institute, a residency in a science-rich center, a seminar for new teachers, a teacher study or action research group, or a teacher network. It is the nature of the learning situation that is important, not the structure.

## PROFESSIONAL DEVELOPMENT STANDARD C:

**Professional development for teachers of science requires building understanding and ability for lifelong learning. Professional development activities must**

- **Provide regular, frequent opportunities for individual and collegial examination and reflection on classroom and institutional practice.**
- **Provide opportunities for teachers to receive feedback about their teaching and to understand, analyze, and apply that feedback to improve their practice.**
- **Provide opportunities for teachers to learn and use various tools and techniques for self-reflection and collegial reflection,such as peer coaching, portfolios, and journals.**
- **Support the sharing of teacher expertise by preparing and using mentors, teacher advisers, coaches, lead teachers, and resource teachers to provide professional development opportunities.**
- **Provide opportunities to know and have access to existing research and experiential knowledge.**
- **Provide opportunities to learn and use the skills of research to generate new knowledge about science and the teaching and learning of science.**

The primary job of a teacher is to promote learning, and it follows that teachers themselves are dedicated learners. Lifelong learning by teachers is essential for several reasons. One obvious reason is to keep current in science. Teachers do not leave preservice programs with complete understanding of all the science they will need in their teaching careers, and they need to continue to clarify and deepen their understanding of the science content that is part of their teaching responsibility.

See Professional Development Standard A

Another reason teachers must have the opportunity to continue to learn is made clear by the observation that tomorrow's students will have markedly different needs from today's students; even today's employers require employees who can frame problems and design their own tasks, think critically, and work together.

Teaching itself is complex, requiring constant learning and continual reflection. New knowledge,skills, and strategies for teaching come from a variety of sources—research, new materials and tools, descriptions of best

See Professional Development Standard B

practice, colleagues, supervisors, self-reflection on teaching, and reflection on the learning of students in the classroom. Teachers continually consider and contribute to the advances in the knowledge base of teaching and learning.

## KNOWLEDGE FOR LIFELONG LEARNING

From their first days considering teaching as a profession through their entire careers, teachers of science develop the skills to analyze their learning needs and styles through self-reflection and active solicitation of feedback from others. They must have the skills to use tools and techniques for self-assessment (such as journal writing, study groups, and portfolios) and collaborative reflection strategies (such as peer coaching, mentoring, and peer consulting). Teachers of science should be able to use the *Standards* and district expectations to set personal goals and take responsibility for their own professional development.

Learning is a developmental process that takes time and often is hard work. As does any professional, teachers of science will stumble, wrestle, and ponder, while realizing that failure is a natural part of developing new skills and understanding. However, effective teachers know how to access research-based resources and, when faced with a learning need, pursue new knowledge and skills that are based on research or effective practice. Teachers of science need to develop the skills to conduct research in their classrooms on science teaching and learning and be able to share their results with others.

## LEARNING SKILLS FOR LIFELONG LEARNING

The integrated knowledge needed to teach science well is developed over time. Thus, the acquisition of the skills for continuous learning should be an explicit component of all learning experiences.

As lifelong learners, teachers need to reflect on their experiences and have techniques and the time to do so. Preservice courses must allocate time to teach prospective teachers techniques for reflection, and practicing teachers must be given opportunities to develop these skills as well. Many techniques for reflection on practice are available, and their use is becoming more widespread. Self-reflection tools such as journals, audiotapes or videotapes, and portfolios allow teachers to capture their teaching, track their development over time, analyze their progress, and identify needs for further learning. Other techniques include peer observation, coaching, and mentoring beginning teachers in either structured or unstructured settings. Teachers also need opportunities to form study groups or hold less-formal sharing sessions.

Continuous learning is an active process that will require different norms from those that are presently operative in colleges and in schools: norms of experimentation and risk-taking, of trust and collegial support, and, most relevant to science, of careful and dedicated inquiry. Schools in which risk-taking is encouraged will provide learning communities for adults as well as for students. Other learning environments that can provide such conditions are professional networks—collegial groups where teachers find help, support, ideas, strategies, and solutions to their problems. Examples include professional science-teaching associations, state and local organizations, and telecommunications networks. Those types of groups provide safe and rich learning environments in which teachers can share resources, ask and address hard questions, and continue to learn.

See Program Standard D and System Standard D

Being a lifelong learner also requires that teachers have the resources for professional development and the time to use them. Such resources include access to formal and informal courses that allow them to keep abreast of current science, access to research on curriculum, teaching, and assessment found in journals and at professional meetings; media and technology to access databases and to analyze teaching; and opportunities to observe other teachers. Conducting formal and informal classroom-based research is a powerful means to improve practice. This research includes asking questions about how students learn science, trying new approaches to teaching, and evaluating the results in student achievement from these approaches. Conducting such research requires time and resources.

**PROFESSIONAL DEVELOPMENT STANDARD D:**
**Professional development programs for teachers of science must be coherent and integrated. Quality preservice and inservice programs are characterized by**

- **Clear, shared goals based on a vision of science learning, teaching, and teacher development congruent with the *National Science Education Standards*.**
- **Integration and coordination of the program components so that understanding and ability can be built over time, reinforced continuously, and practiced in a variety of situations.**
- **Options that recognize the developmental nature of teacher professional growth and individual and group interests, as well as the needs of teachers who have varying degrees of experience, professional expertise, and proficiency.**
- **Collaboration among the people involved in programs, including teachers, teacher educators, teacher unions, scientists, administrators, policy makers, members of professional and scientific organizations, parents, and business people, with clear respect for the perspectives and expertise of each.**
- **Recognition of the history, culture, and organization of the school environment.**
- **Continuous program assessment that captures the perspectives of all those involved, uses a variety of strategies, focuses on the process and effects of the program, and feeds directly into program improvement and evaluation.**

See Program Standard A

The professional development of teachers is complicated: there is much for teachers of science to know and be able to do; materials need to be critiqued and questions need to be researched; a variety of information and expertise needs to be tapped; and many individuals and institutions claim responsibility for professional development. However, for an individual teacher, prospective or practicing, professional development too often is a random combination of courses, conferences, research experiences, workshops, networking opportunities, internships, and mentoring relationships. More coherence is sorely needed.

Professional development programs and practices require a focus on the vision of science education presented by the *Standards*. Attention must be paid at the state, district, and college and school levels to fitting the various pieces of professional development programs together to achieve a common set of goals. Preservice program coordination requires mechanisms and strategies for connecting and integrating science courses, pedagogy courses, and clinical experiences (i.e., experiences in schools and classrooms). Such coordination also is needed for programs for practicing teachers, who often face myriad offerings by school districts, individual schools, professional associations, unions, business and industry, regional service centers, publishing companies, local universities, nearby research laboratories, museums, and federal and state agencies.

**See System Standards A and B**

Professional development opportunities for teachers must account for differing degrees and forms of expertise represented in any group, and they must recognize the nature of quality experiences as described in standards A and B. Programs must be designed not just to impart technical skills, but to deepen and enrich understanding and ability. Professional development activities must extend over long periods and include a range of strategies to provide opportunities for teachers to refine their knowledge, understanding, and abilities continually.

Individual teachers of science should have the opportunity to put together programs for professional development, as should groups of teachers, whether formally constituted or informally connected through common needs and interests. The many providers of teacher professional development activities will continue to design programs. However, the strongest programs result from collaborations among teachers, developers (such as university faculty, science coordinators, and teachers), and other stakeholders (including community agencies, science-rich centers, scientists, school administrators, and business and industry). Such collaborations increase coherence, and they bring a wide variety of expertise and resources to bear on a set of common goals that are directly connected to the needs of teachers.

The success of professional development for practicing teachers is heavily dependent on the organizational dynamics of schooling, such as a climate that permits change and risk-taking, good relationships among school personnel, communication structures, and an appropriate distribution of authority. Professional development programs therefore must involve administrators and other school staff. All must be committed to ensuring that prospective teachers, new teachers, and practicing teachers who wish to implement new ideas as part of their professional development are supported and integrated into the ongoing life of the school.

Finally, those who plan and conduct professional development programs must continually evaluate the attainments of teachers and the opportunities provided them to ensure that their programs are maximally useful for teachers.

## CHANGING EMPHASES

The *National Science Education Standards* envision change throughout the system. The professional development standards encompass the following changes in emphases:

| LESS EMPHASIS ON | MORE EMPHASIS ON |
|---|---|
| Transmission of teaching knowledge and skills by lectures | Inquiry into teaching and learning |
| Learning science by lecture and reading | Learning science through investigation and inquiry |
| Separation of science and teaching knowledge | Integration of science and teaching knowledge |
| Separation of theory and practice | Integration of theory and practice in school settings |
| Individual learning | Collegial and collaborative learning |
| Fragmented, one-shot sessions | Long-term coherent plans |
| Courses and workshops | A variety of professional development activities |
| Reliance on external expertise | Mix of internal and external expertise |
| Staff developers as educators | Staff developers as facilitators, consultants,and planners |
| Teacher as technician | Teacher as intellectual, reflective practitioner |
| Teacher as consumer of knowledge about teaching | Teacher as producer of knowledge about teaching |
| Teacher as follower | Teacher as leader |
| Teacher as an individual based in a classroom | Teacher as a member of a collegial professional community |
| Teacher as target of change | Teacher as source and facilitator of change |

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