

COLLEGE PATHWAYS to the

Science Education Standards

Edited by Eleanor D. Siebert and William J. McIntosh

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Preface

Wanted: *College and university science teachers wishing to become engaged in a comprehensive, important, and potentially transforming educational movement. Those who accept the challenge will join with K–12 teachers in a quest to give every American an essential understanding of the physical and biological processes that characterize our world, and to nurture curiosity and scientific habits of mind. In the process, all participants will experience change and renewal.*

A job announcement such as the above might describe what is in store for higher education faculty who internalize the principles and practices recommended by the *National Science Education Standards*. Although the *Standards* were written to specifically address science education in grades K–12, the job of transforming science education and achieving a scientifically literate public is so important that the *Standards* have special significance for higher education science faculty as well. As postsecondary teachers of science, we cannot be complacent in the belief that the way we have been teaching will empower our students to function effectively in the world of today and tomorrow.

Attention is focused on the need for change in science education because so many Americans—from children to adults—do not have a correct understanding of basic science concepts and processes and are, therefore, ill-equipped to make critical decisions in areas such as health and medicine, the environment, and biotechnology. More sadly, many are unable to appreciate the intricate wonder that is our Earth. Another driving force of the reform movement is the accelerating need for individual and national competence and competitiveness in a global economy that is increasingly based on science and technology. Mediocre science scores on international achievement tests such as the Third International Mathematics and Science Study (TIMSS) underscore the need for a comprehensive approach to changing the way that science is taught and learned.

The *National Science Education Standards* provide a comprehensive guide to move us toward achieving a scientifically literate nation. These standards are based on our current, research-based understanding of the teaching-and-learning process, common perceptions (including misperceptions) of scientific concepts, and the role of prior knowledge in learning. Hundreds of teachers, scientists, science educators, and administrators from across the country collaborated on the *National Science Education Standards*, which suggest both what students should know and be able to do at each developmental level and how we can align curriculum, instruction, and assessment to help them achieve these expectations. The *Standards* also address systemic issues of teacher preparation, professional development, the quality of school programs, and the entire educational system as a context for K–12 reform.

University and college professors of science are an integral part of this educational system because it is, in very large part, from our courses that society will learn its science. The lessons and experiences we provide will be passed to future generations—by way of our majors who enter fields of science and technology and by way of those nonmajors who make policy and those who approve it. The *Standards* ask that we approach this task differently than we have in the past.

We must also note the important role we play regarding our students who are preparing to become K–12 teachers. The responsibility of preparing teachers lies primarily with higher education, and here faculty members in both science and education have significant roles. The responsibility of science faculty members is to develop not only the science knowledge of our students, but also their understanding of the nature of science, their ability to understand and use scientific ways of thinking, and their ability to make connections and apply what they know to the world outside the science classroom. The responsibility of education faculty members is not only to provide fundamental information and skills related to teaching and learning, but also to mentor teachers in their ability to actively study and reflect on what they do and use their own research to make informed decisions about the appropriateness of curriculum, instruction, and assessment in their own classrooms.

The purpose of this book is to present and interpret the *Standards* in ways that are meaningful to higher education faculty members, especially those who teach science. The Teaching Standards and the Assessment Standards (Chapters 1 and 3) are the focal points of the book. The Professional Development Standards (Chapter 2) as presented in this book carry a dual message. First, they speak to science faculty about ways to develop their own teaching skills so as to maximize learning opportunities for students; second, they serve as a guide to faculty members who are in-

volved in providing professional development for others, emphasizing deep learning and genuine conceptual understanding rather than superficial exposures. The Content Standards (Chapter 4) are foundations upon which college instruction can build. The Science Education Program Standards (Chapter 5) articulate criteria that can be used to create excellent science programs at the postsecondary level, and the Science Education System Standards (Chapter 6) consider external factors that affect science program development and implementation.

In each chapter, short essays address the implications for college science teaching of each Standard, and there are detailed illustrations—“From the Field”—of how *Standards*-based teaching is being implemented in undergraduate science courses. For readers interested in pursuing further the concepts discussed in this book, we provide reference lists in each chapter.

Throughout the book, we have tried to maintain the original emphasis of the *National Science Education Standards* and to convey their central vision. We agree that at the college level as well as in K–12 *all* students can learn science; consequently, we include suggestions for teaching nonscience majors and students with special needs. We also believe that science should be an active process that engages students both intellectually and physically—*especially* at the introductory level. To illustrate this approach, we have asked colleagues to share ways they have structured courses for maximum student involvement.

College Pathways to the Science Education Standards is full of ideas, examples, and suggestions. As such, it is an appropriate resource for many audiences. For example, while the book is directed explicitly to postsecondary teachers of science and science educators, it will be useful to high school teachers of advanced placement courses and to preservice teachers and graduate students as they begin their classroom careers. There is no one way to use this resource. It should raise questions and stimulate thinking about what and how we teach, and how we might study and improve what we do. We hope it will elevate consideration of the implications of the *National Science Education Standards* for postsecondary science teaching and, in so doing, encourage readers to develop and grow in their understanding of the teaching-and-learning process.

Acknowledgments

This National Science Teachers (NSTA) publication on the impact of the *National Science Education Standards* on higher education has been a long time coming; it was conceived by the 1996 NSTA Committee on College Science Teaching. Chairperson Gerald Krockover and Bill McIntosh, then president of the Society for College Science Teachers, agreed to an overall plan for the publication, and Bill became editor of the book. The 1997-99 Committee on College Science Teaching continued the project with its chairperson, Eleanor Siebert, becoming co-editor of the project. The 1999-2000 committee members (Bill McIntosh, chairperson) served as readers of the document as the manuscript developed.

This book has truly been a labor of love. Ultimately its value stems from the vignettes provided by the more than forty dedicated science teaching faculty and others who are profiled at the end of the book. Thanks to our chapter coordinators for their persistence in soliciting articles in their areas of expertise: Joseph Stepan, a member of the 1996 College Committee, who coordinated the contributions to the chapter on professional development; Judith Heady, who culled many references and gathered many vignettes pertaining to assessment; Mario Caprio, who brought together many resources and perspectives in his chapter on the higher education system; and Bill Leonard, who provided the Epilogue.

The names of many members of the NSTA College Committees who contributed to the book are included within these pages; others include Daniel Domin, George Randall, and Jeffery Schultz, whose ideas are included in the text and who served as readers during the development phase of the manuscript. We have benefited greatly from the careful review and suggestions of Donald French, Eric Packenham, Harold Pratt, and Jeffrey Weld.

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Also at the NSTA, Linda Olliver designed the cover and the book's layout; Jack Parker, Nguyet Tran, and Catherine Lorrain-Hale handled production; and Catherine Lorrain-Hale coordinated the printing of the book. Beth Daniels, Anne Early, Jessica Green, and Claudia Link provided additional, invaluable assistance.

Eleanor D. Siebert

William J. McIntosh

Introduction

A Vision of Scientific Literacy

Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity. (NRC 1996, 22)

The Nature of Science

Science provides a way for us to understand the world in which we live. Scientists ask questions, then search for answers to those questions. While there are many pathways that can be taken in the search for an answer to a particular question, for scientists all ways are based on observations, inferences, and testing. Referred to as “the scientific method,” these processes are the hallmarks of a method that produces creative and valid interpretations of events. During questioning for jury service recently, a judge asked one of the editors of this book whether she would be able to contend with uncertainties since she had been trained as a scientist to deal objectively with evidence about which there is no uncertainty. This judge’s impression was that scientists work with the “black and white” issues of our world, while human judgments in dispensing justice must enter a “gray” area.

This story confirms that members of the public, including those who are well educated, often do not understand the nature of science. It has been well documented that many people do not comprehend fundamental concepts and processes of science and thus cannot appreciate the work that scientists do. Why is an understanding and appreciation of science important? In 1983, a report prepared by the National Commission on Excellence in Education (NCEE) entitled *A Nation at Risk: The Imperative for Educational Reform* (NCEE 1983) focused on the importance of

science in developing and sustaining economic growth in the United States. Perhaps even more importantly, John A. Moore has argued that without an understanding of science, it is virtually impossible to appreciate the beauty and wonder of the world around us (Moore 1993). Finally, in a society where life is increasingly dominated by technology enabled by scientific discoveries, it is important to have a scientifically literate society—a populace that can make intelligent personal and political decisions.

If an understanding and appreciation of science is important to quality of life and to sustaining economic growth, how do we ensure a scientifically literate populace? Many argue that a cultural shift is required. One place to begin that shift is in school classrooms across the nation. Students must come to understand the nature of science, be familiar with the fundamental concepts that connect the science disciplines, and know how to apply those concepts in the process of making decisions. This cultural shift will take years to attain and will happen only if there is a public consensus that the goal is valid—and only if the educational community has a shared vision for how to reach that goal.

Changing the Way That Science Is Taught in the K–12 Classroom

In *A Nation at Risk* (NCEE 1983), the National Commission on Excellence in Education predicted that the United States would soon be engulfed in a “rising tide of mediocrity.” The report provided a rationale and background for program shifts in funding priorities at the National Science Foundation. Education programs that emerged included the Eisenhower Program and systemic reforms. The report was followed in 1989 by President George Bush’s national education meeting at the National Governors’ Conference. The governors set national education goals for science, technology, and mathematics; Goal 4 stated that by the year 2000, children in the United States would rank number one in understanding science and mathematics. Unfortunately, a coherent national plan to achieve these goals was not developed at that time.

In 1989, the American Association for the Advancement of Science (AAAS) published *Science for All Americans* (AAAS 1989), a study that argued that *all* students could be and should be expected to learn science. This initial publication of AAAS’s Project 2061 marked the adoption of a long-range plan for achieving scientific literacy. In 1993, AAAS published *Benchmarks for Science Literacy*, which outlined the hallmarks of a plan to achieve scientific literacy in the schools. In 1989 the National Science Teachers Association (NSTA) began work on a curriculum project called

“Scope, Sequence, and Coordination of Secondary School Science,” which integrated concepts across science disciplines to build a coherent understanding of science for children in the middle grades; the project was tested extensively at that level across the nation. Its success is documented by the National Science Teachers Association (NSTA 1992) and Aldridge (1996), although it did not achieve nationwide acceptance.

Most of these projects are still in progress, but a more comprehensive approach was needed in order to provide a coherent national vision for science education, particularly at the K–12 level. In 1992 the National Research Council of the National Academy of Sciences convened a committee to consider the articulation of national standards for science education. Three working groups, composed of teachers, administrators, science education specialists, and scientists, were established to write standards: One group focused on content standards, a second on teaching standards, and a third on assessment standards. When a draft document was finally produced after a long dialogue, it was sent out to thousands of teachers on all levels for their input before the final revision was made. The document we have today is the closest the United States has ever come to having a comprehensive national vision of science education.

Not only are the *National Science Education Standards* based on consensus, they are based on research. The Teaching, Professional Development, Assessment, Content, Program, and Systems Standards reflect current best practices derived from advances in education and the cognitive sciences. As new information becomes available about teaching and learning, revisions will undoubtedly be required. Right now, though, it is the best document we have to inform science teaching. After extensive critique and review lasting approximately two years, the *National Science Education Standards* were published in December 1995.

A Vision for Science Education

The overarching goal of the *National Science Education Standards* is to provide for an education system that prepares a scientifically literate society. *Scientific literacy* is defined in the *Standards* as “the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity” (NRC 1996, 22). On the surface this statement seems to represent a reasonable goal for the majority of students. But, on reflection, one realizes that the achievement of scientific literacy is actually a lifelong process that is built on years of formal and informal instruction and experiences. In this sense, college science courses, especially for nonmajors, influence just a small fraction

of a person's lifelong pursuit of scientific literacy. But when these courses build on a coherent and solid science background gained in K–12, the college science experience can be one that enriches people's lives. The powerful ideas that captivate and energize us as scientists can similarly change forever the way students view the world in which they live. However, what students learn and understand about the content and processes of science is greatly influenced by how they are taught.

The *National Science Education Standards*, which provide guidelines for how science should be taught, are based on four guiding principles, which may be paraphrased as follows (see NRC 1996, 9):

- Science is for all students.
- Students learn best by active participation in the learning process.
- Education should reflect the way that science is done.
- Improving science education requires a coordinated effort of *many* stakeholders to change the complex educational system. Stakeholders include teachers, supervisors and local communities, administrative personnel, policymakers, assessment specialists, curriculum developers, science educators, and more.

These four principles have important implications for science teaching—not only for grades K–12, but for the postsecondary years as well—and will be apparent in the narrative throughout this book. Three important terms from the field of educational research that are identified with these principles (and used throughout this book) are *constructivism*, *active learning*, and *inquiry approach*.

Constructivism. Science is most likely to be accessible to all students when students are engaged in the learning process and when they can see the importance of science in everyone's lives. Instructors need to recognize that students construct knowledge based on previous understanding and experience. This theory of learning is called *constructivism*, according to which students construct new understanding on an existing framework of knowledge (Lorsbach and Tobin 1993; Yager 1991; Bodner 1986). The basic premise of constructivism is that knowledge is built by the learner. That is, a person's knowledge of the world is developed over time through experiences that build upon what a person already knows. Thus each person's view of the world is unique. Modern constructivism, which can be traced back to Swiss psychologist Jean Piaget, is interpreted differently by different camps and as such is the subject of much debate. However, in spite of the lack of consensus regarding philosophical details, constructivist teaching models have evolved. These models redefine the teacher as a facilitator of learning rather than a disseminator of information and the student as an active participant in his or her own learning. Figure i.1 shows three of the fundamental differences between traditional and constructivist classrooms as presented by Brooks and Brooks (1993).

Figure i.1

Fundamental Differences between Traditional and Constructivist Classrooms

Traditional Classrooms	Constructivist Classrooms
Students are viewed as “blank slates” onto which information is etched by the teacher.	Students are viewed as thinkers with emerging theories about the world.
Teachers generally behave in a didactic manner, disseminating information to students.	Teachers generally behave in an interactive manner, mediating the environment for students.
Assessment of student learning is viewed as separate from teaching and occurs almost entirely through testing.	Assessment of student learning is interwoven with teaching and occurs through teacher observations of students at work and through student exhibitions and portfolios.

Source: Brooks, J. G., and M. G. Brooks. (1993) *The Case for Constructivist Classrooms*. Alexandria, VA: ASCD, 17.

A good constructivist science lesson, according to Saunders (1992) is one in which students are “thinking out loud, developing alternative explanations, interpreting data, participating in cognitive conflict, developing alternative hypotheses, designing further experiments to test alternative hypotheses, and selecting plausible hypotheses from among competing explanations” (140).

Active Learning. The principle of active participation indicates that students cannot be passive in the learning process. For example, Angelo (1990) has shown that students retain on average only 20 percent of what they hear in a lecture class. If learning is to occur in the classroom, science lessons must actively involve students both mentally and physically (Bybee 1993). Student activity, or *active learning*, needs to supplant the more traditional lecture approach to teaching.

Inquiry Approach. The inquiry approach to learning is based on the idea that science education should reflect the way that science itself is carried out. Inquiry can be defined both as a learning goal and an instructional strategy. As a learning goal, inquiry includes both the abilities to do scientific inquiry and a set of understandings about scientific inquiry. The abilities referred to are those that scientists commonly use to investigate their world. Understandings of scientific inquiry represent “how

and why scientific knowledge changes in response to new evidence, logical analysis and modified explanations debated with a community of scientists” (NRC 2000, 21). One understanding, for example, might be the following:

Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modifications; and it must be based on historical and current scientific knowledge. (NRC 2000, 20)

Inquiry-based teaching and learning draw on instructional strategies that have the following essential features:

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented problems.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations. (NRC 2000, 25)

As one might imagine, inquiry teaching and learning require students to be physically active and mentally engaged. Inquiry lessons can emerge in the classroom and in the laboratory.

The *National Science Education Standards* recognize that the responsibility for change requires a coordinated effort of many parties in order to be successful. In grades K–12, support for the teacher—and students—must come from administrative personnel (principals, superintendents), policymakers (school boards, government agencies), and the community (especially parents and businesses). At the undergraduate level, one can identify similar entities that will be necessary to foster widespread change in science teaching. Academic institutions will need, for example, to provide support for and recognition of quality teaching, as well as to seek ways to enhance communication with external communities and policymakers. Academic departments will need to encourage coordination among science programs, and scientists and professional societies will be important players in creating and sustaining change in science teaching at the postsecondary level.

A Role for Higher Education

The goal of the *National Science Education Standards* is to achieve scientific literacy, and perhaps the best place to begin this process is in K–12 science classrooms, but this book supports the argument that higher education must be involved in changing the way that science is taught in K–16 and beyond. To support change in K–12, we must change the way that science is taught at the college level. We need to examine the way we teach *all* of our courses—the courses for science majors and health professionals, general science courses for nonscience majors, and preservice courses for future teachers. Each of these types of courses affects our citizenry—as our students become teachers, health professionals, manufacturers, parents, and so on. These are the people who will guide the future of society’s endeavors, and they will base their decisions on their understanding of science and technology and its impact in their lives. Among the very important courses that we teach are those in which future K–12 teachers are enrolled; the students in these courses can exponentially expand the effect of a single college science course when they in turn teach young children in their most formative years. The preservice courses and the future teachers they serve will, in large part, determine the nation’s comfort with, knowledge about, and interest in science.

A legitimate question to ask is, *Why is change important now?* There are many answers to that question. For example, the science that we communicate to our students is highly complex; decisions facing our citizenry need to be based on an understanding of science and technology; and, importantly, our students have changed. The life experiences of our students are not those that most teachers of science faced during their own formative years; in fact, the experiences of young adults today are significantly different from those of only ten years ago. Science and technology are shaping our evolving environment, and we must enable our students to make decisions and to participate effectively in the “new” world.

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Teaching Standards

William J. McIntosh

The vision portrayed by the *National Science Education Standards* (NRC 1996), referred to here as the *Standards*, recognizes our emerging understanding of the teaching-and-learning process. The vision is one in which effective teachers of science “create an environment in which they and the students work together as active learners” (NRC 1996, 28). This environment supports close student-teacher interaction and provides an opportunity to develop inquiry skills as a means of achieving scientific literacy. The research-supported vision of the *Standards* does not support the practice in institutions of higher education by which instructors lecture to groups of students who subsequently verify the concepts and principles in the laboratory. Although huge lecture halls and verification labs may be cost-effective, they are an ineffective means for students to learn concepts and practice science (Lord 1994; Leonard 1992). We know from cognitive psychology, for example, about the importance of providing opportunities for students to construct their own knowledge. A growing body of research supports the notion that misconceptions that students bring to a learning environment may interfere with the acquisition of new knowledge. Researchers have found, however, that specific teaching techniques can be used to change those misconceptions (Posner et al. 1982).

The *Standards* vision guides the discussion in this chapter on science teaching standards for the postsecondary level. The discussion centers on the importance of goal setting, designing experiences to meet students’ needs, assessment, and collegiality. There is a strong recommendation that students be given opportunities to engage in meaningful scientific inquiry—to ask scientific questions, design experiments to collect evidence, and make critical interpretations of observations.

The ideas in this chapter and in the *Standards* challenge the traditional notion of the role of lectures in college science teaching. The authors whose work you are about to read—in the From the Field vignettes—are currently engaged in developing the practices about which they write. Their interpretations of the *Standards* offer us insights about how we can most effectively guide our students along the pathway to scientific literacy.

Planning an Inquiry-Based Science Program



Teachers of science plan an inquiry-based program for their students. In doing this, teachers

- Develop a framework of yearlong and short-term goals for students.
- Select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students.
- Select teaching and assessment strategies that support the development of student understanding and nurture a community of science learners.
- Work together as colleagues within and across disciplines and grade levels.

Source: National Research Council. (1996) *National Science Education Standards*. Washington, DC: National Academy Press, 30.

A central tenet of the *National Science Education Standards* is teaching science as inquiry, as discussed in the Introduction to this book. The effectiveness of inquiry as an instructional strategy has been well-documented across grade levels (Haury 1993). In a major study of college-level physics courses, Hake (In press) concluded that “the use of IE (Interactive Engagement) strategies can increase mechanics-course effectiveness well beyond that obtained with traditional methods.” Hake’s IE strategies closely align with a definition of “inquiry.”

College instructors, like their K–12 counterparts, are addressing Teaching Standard A by looking more critically at the content of the courses they teach. In many cases higher education faculty are restructuring their courses to provide students with opportunities to pose and investigate researchable questions (Harker 1999; Weld, Rogers, and Heard 1999). They are doing so because, for all students, the development of scientific inquiry skills becomes an important component of their scientific literacy and problem-solving abilities. For science majors, effective scientific inquiry skills are a critical link between their K–12 science education and their careers or graduate research. It is especially important that students intending to major in the sciences improve on these abilities at the introductory college level in order to lay the foundation for upper-level course work.

Providing inquiry experiences in a college-level science course requires a different kind of planning than many higher education faculty members are used to. The planning starts with focusing on course goals that reflect both content and inquiry skills to be mastered. The nature of the experiences in which students will be engaged during the semester is defined; the experiences are chosen less by tradition than by appropriateness to course content and inquiry skills to be developed. In many cases students themselves choose questions that they are interested in and

that they wish to investigate. College-level inquiry experiences, for example, can range from problem-based learning (Duch 1996), where students are given the opportunity to solve real world problems, to inquiry labs (Glasson and McKenzie 1998), where students design and conduct their own investigations.

Once goals are established, the logistics of inquiry teaching are addressed. In many large enrollment courses the lecture component generally focuses on content while the laboratory activities focus on science as an active process. In a smaller enrollment course, lecture and laboratory may be integrated to achieve similar goals. The best results seem to come about when students build competency with the scientific process in a stepwise fashion. In that scenario, an experimental sequence is planned that builds in complexity. Students begin by designing experiments to test relatively simple hypotheses and later to examine more complex ones. Laboratory instructors may lead discussions to help the students generate hypotheses that would be feasible to test within the constraints of budget, space, materials, personnel, and time. Students generate research questions, design experiments, collect data, and reach conclusions. They generally work collaboratively; in some cases, each member of a laboratory team is responsible for presenting an oral report on his or her aspect of the topic and illustrating his or her presentation with a poster.

Proper planning for inquiry-based learning is labor intensive for the course instructor, teaching assistants, and even the students. A great deal of effort must go into preparing experimental materials, critiquing protocols, supervising students, and mentoring teaching assistants to be good scientific inquiry coaches. However, students who design their own experiments report having a heightened sense of ownership, which in turn increases their motivation and interest in science (Stukus and Lennox 1995). Professors note that most students become highly involved in their research, teaching assistants are enthusiastic about teaching the course, and students' scientific inquiry and problem-solving skills improve.

From the Field

Changing Student Attitudes about Science through Inquiry-Based Learning

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I have been teaching sophomore/junior-level undergraduate science courses for nearly thirty years and have taken students with strong negative at-

titudes toward science and helped them to have positive learning experiences. A key to changing attitudes is to *engage* students in learning science.

I have used three techniques of engagement simultaneously: inquiry-based learning, relating science to career choices, and making important connections between science and other academic disciplines.

I begin my course with a presentation to students about the relevance of science and of this course to their career choices—whether that choice is education, liberal arts, engineering, or agriculture. Then we discuss ways of knowing and learning science. Members of the class work in collaborative science teams of five to six students each and focus their efforts on laboratory experiences for learning science. We stress the importance of using questions, developing hypotheses, conducting experiments, and collaborating with colleagues. We also stress connections between the sciences and mathematics, particularly by developing skills such as measuring and graphing and using technology and application software.

Maintaining contact among class members outside of class is essential to building a community of learners.

Thus, we keep in touch with each other via e-mail and the Internet so questions can be asked anytime not only of the instructor, but also of other students. I also have previous years' students online to serve as resources. And students participate in one field trip each term to emphasize the relation of course content to real problems. The trips became a course focus some years ago when a survey indicated that 95 percent of the students in my introductory course had not taken a field trip since elementary school.

As a result of these experiences, more than 1,800 of my students have modified their attitudes toward science. These students are confident that they can learn science content in an inquiry-based environment, relate science to their career choices, and make connections to other science and nonscience disciplines. They know that inquiry into authentic science questions has helped them to develop skills for lifelong learning. And, isn't this what college science teaching is all about?

Guiding and Facilitating Learning



Teachers of science guide and facilitate learning. In doing this, teachers

- Focus and support inquiries while interacting with students.
- Orchestrate discourse among students about scientific ideas.
- Challenge students to accept and share responsibility for their own learning.
- Recognize and respond to student diversity and encourage all students to participate fully in science learning.

- Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

Source: National Research Council. (1996) *National Science Education Standards*. Washington, DC: National Academy Press, 32.

Teaching Standard B supports Teaching Standard A in that it addresses the nature of student-teacher interactions that support inquiry learning. Higher education faculty who meet this Standard guide and facilitate learning by recognizing the worth of all students and by communicating with them on a level that challenges their thinking and piques their curiosity. This can be accomplished in a small class by coordinating group discussions and relevant activities by which students carry out meaningful, inquiry-oriented tasks. Instructors skillfully weave content and inquiry skills as they model the kinds of thinking students are expected to exhibit. However, as one might imagine, this methodology poses a formidable (though not insurmountable) challenge in large enrollment classes.

In the laboratory, this inquiry-based instructional mode places both the instructor and the student in new roles (Glasson and McKenzie 1998). The students are actively engaged in the “minds-on” activity of designing experimental procedures. The instructor’s role changes from being an authority figure who clarifies procedure and tells students whether they have the right answer to that of a facilitator: someone who interacts with the students to foster cognitive growth by asking them questions and guiding them in their inquiries.

In addition to guiding and supporting student inquiries, the facilitator encourages all students to participate fully in their learning while respecting and appreciating the qualities other students bring to the learning environment. One way to do this is to have the students work in small groups. Each group member has a role (e.g., leader, scribe, technician, or counselor) and shares in the responsibility of the learning process (Duch 1996). Role assignments change for each activity, thus preventing one person from dominating the group. This cooperative arrangement also helps students reflect on their strengths and weaknesses and encourages discussion among students. Within a group, students debate and justify ideas; conceptual understanding is reinforced as students try to persuade other group members of the validity of their ideas. To encourage group work, opportunities must be provided for the group members to meet and discuss the activity.

Group presentations are another way to encourage discussion among students. By presenting their work in an open forum, the students are given the opportunity to express their ideas and to debate their conceptual understanding of scientific ideas and methodologies. Students must not only persuade others that their work is meaningful, but also justify what they have done.

Higher education faculty who act as facilitators encourage students to accept and

share responsibility for their own learning. They interact with students as much as possible by asking questions, facilitating discussion, and challenging students to clarify ideas and draw conclusions. This instructional environment provides the students with a glimpse of what characterizes science. Much of science involves the art of persuasion: using data and one's conceptual understanding to convince others of the soundness of one's ideas. Criticism and debate are important, as it is through these processes that validity and meaning are established.

Science is more than replicating the works of others. It requires an openness to investigation, and the path to be taken is not always clear at the outset. Students can understand this concept with the help of faculty who view themselves as facilitators of learning as well as purveyors of knowledge.

From the Field

Identifying and Using Learning Styles to Facilitate Instruction

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At the beginning of the 2000 fall semester, faculty members at our college who taught introductory biology gathered to plan for coming classes. One professor who had attended a Project Kaleidoscope (see page 135) summer workshop boldly announced what many of us had come to suspect: "The emperor has no clothes," she said. "We are teaching but our students are not learning. We must change." And change we did.

The introductory biology professors decided that knowledge of how each student learned would help us as instructors and empower our students to direct changes in our pedagogical techniques. In pursuit of those goals, I designed the following cooperative venture. I began the process by telling my students about the conversation and events that had led

to the need for change in the course structure. To teach them more effectively, I said, I needed their help. I went on to explain that each of them was a unique learner: They each had their own style of learning and their own learning experiences. To help them understand introductory biology, I would need to know about these learning styles and experiences. I challenged my students to accept and share responsibility for their own learning and "do science" at the same time. They accepted the challenge.

My first step was to educate both my students and myself about learning style theory. I used my course Web site at *Blackboard.com* to link to a site where each student would take the NC State Index of Learning Styles Questionnaire, www2.ncsu.edu/unity/lockers/users/ff/felder/public/ILSdir/

ilsweb.html, online and free-of-charge. The site also provided us with two articles that contained in-depth explanations of theories of learning styles and their practical applications. As the professor, I was responsible for providing copies of the articles. After reading the articles, each student formed a hypothesis as to what the inventory would show her or his learning style to be. Students then took the inventory and printed out two copies of their results. One copy was placed in each student's file; the other was kept by the student. When all students had completed the assignment, they brought the results to class. Each student presented her or his results to the class and compared the inventory results to her or his hypothesis. Much discussion ensued. Some agreed with the inventory results and some did not. The students drew up conclusions as to how they would alter note taking, classroom questioning, and study habits as a result of the inventory. Each student's hypothesis, process, results, and discussion were combined in a written report that was turned in to me. We also discussed the changes that I would have to make in my classroom presentation in order to support the learning styles of all students.

In the true spirit of scientific research we quantified our results. We compiled total class results using Microsoft Excel to create tables and graphs of our data. Students unfamil-

iar with Excel were responsible for arranging tutorials with me or with classmates. Numerous e-mails followed as students explored how to graph and what graphs were most illustrative of the data gathered. The resulting graphs were included in their written reports.

The introduction of learning style theory, the cooperative investigation, and the inventory results significantly altered the nature of student-professor interaction in my class. Whereas students had formerly asked me simply to repeat material or to provide further explanation when they were confused, now their requests became much more specific and helpful to me. Students now asked if they could be provided with graphics, models, or sequential explanations to help them understand a concept. Oftentimes they cited their learning styles as justifications for their requests. Additionally, students began to help their peers. More important to me were their suggestions as to how I might alter a learning experience in order to address the styles of classmates.

I was thrilled when non-biology majors and students from other colleges began to access my site to take the inventory. However, my greatest reward came when several of my students commented, "Why haven't we been told this before? Everyone needs to know this!" Now, one hopes, everyone will.

Linking Assessing, Learning, and Teaching



Teachers of science engage in ongoing assessment of their teaching and of student learning. In doing this, teachers

- Use multiple methods and systematically gather data about student understanding and ability.
- Analyze assessment data to guide teaching.
- Guide students in self-assessment.
- Use student data, observations of teaching, and interactions with colleagues to reflect on and improve teaching practice.
- Use student data, observations of teaching, and interactions with colleagues to report student achievement and opportunities to learn to students, teachers, parents, policy makers, and the general public.

Source: National Research Council. (1996) *National Science Education Standards*. Washington, DC: National Academy Press, 37-38.

Teaching Standard C invites us to consider the important links among assessment, learning, and teaching. A comprehensive assessment of students informs the instructor about student progress toward course goals (learning) and also about the efficacy of the instructor's teaching. Data collected both formally and informally can be used to identify students' prior knowledge and experiences, evaluate their understanding of important concepts being taught, and measure the extent to which students meet course goals. Instructors can use this information, in turn, to make decisions about instruction and subsequent student learning. Quality assessment also can provide students with feedback about their own progress toward course goals.

In general, a good assessment plan is systematic, multiple in form, and at times nonevaluative (see Chapter 3). This Standard distinguishes between the broader terms *evaluation* and *assessment*. In the case of evaluation, students are administered testing instruments for the purpose of assigning grades; assessment of student learning has the dual purpose of providing student feedback and improving the program. This means that assessments should be carefully planned so the feedback is useful for both student and instructor.

Instructors engage in *multiple forms of assessment* when they collect many different kinds of information about their students. Multiple forms of assessment provide a clearer picture of what students know and are able to do. In the classroom, traditional tests, quizzes, and laboratory work are supplemented or replaced by student presentations and products. Students can be asked to demonstrate knowledge application by conducting and presenting the result of long-term scientific investigations; instructors may also design performance assessments, tasks that require application

of skills and knowledge to answer open-ended questions. In other words, students are being asked to think and reason as scientists do.

Other types of assessments include querying students about their knowledge of a subject before instruction in the subject begins. Because students construct new understandings on a preconceived base of knowledge (as discussed in the Introduction), it is important to identify student misconceptions so that instruction can be planned to counter them. Post-course queries can then be used to gauge progress toward goals established by the instructor.

Many instructors, before a major evaluation, engage in frequent and ongoing informal questioning of students that serves to inform both the student and teacher about the extent to which the class is reaching course objectives. This information can help students and instructors to identify difficult concepts that will require additional explanation and study. Faculty should also encourage students to use frequent self-assessments to guide their studies.

The design of assessment tools is discussed in more detail in Chapter 3. In the present chapter, the emphasis is on using carefully planned and frequent assessments in multiple forms to improve teaching. Such assessment data, in conjunction with classroom observations and professional interaction with colleagues, give instructors the information necessary to improve teaching—and student learning. These data also allow us to evaluate student achievement (i.e., assign grades) and to share with others the success of our programs.

In today's college classrooms, faculty are allowing students to demonstrate their understanding in a variety of ways. Multiple assessments access different sensory capabilities and as such are of particular importance to increasing the diversity of successful students in science fields—including, especially, the capable student who has recognized learning challenges and students who come to class with a wide range of cultural experiences (see also Chapter 5, Program Standard E). In short, multiple assessments provide valuable information about students that if used appropriately can guide both teaching and learning.

From the Field

Assessment Techniques to Guide Teaching in Courses with Large Enrollments

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University of Delaware

I have been teaching high-enrollment physics and astronomy courses composed of approximately five hundred students for years—and for many years my assessment of student work involved an hour exam or two and a final examination. Multiple-choice questions and fill-in-the-bubble

answers to artificially concise problems led my students to rely on recall of material covered in class and in the text. I was unhappy with what my students “learned”—and what my assessments indicated were important for them in solving “real-life” problems. Over the past few years I have begun to develop a variety of different assessment techniques. Some of these techniques permit me to assess student work before the traditional hour or final examination in a more systematic way than “reading the faces” in class, or reacting to that uncomfortable atmosphere when students put down their notebooks, stare off into space, and otherwise indicate their disengagement. And importantly, a variety of types of assessments permits students to show what they know in different ways.

A guiding principle that I use in designing assessments is to make the assessments match the real world as much as possible. Given the constraints of a large class and the responsibility to assess the performance of individual students as well as teams, let me describe some of the ways I now assess my students.

Often during the semester, I stop just before the end of the class period and ask each person to take one minute to answer a simple question: “As you think about the topics we have studied so far in this class, what is the most confusing concept or phenomenon that we have studied?” I then collect the answers and read them. I try to clear up the most common points of confusion during the next class peri-

od. The question you ask can vary; Frederick Mosteller of Harvard asks students to identify the “muddiest point” in his statistics classes. This “minute paper” is one of the easiest of the new assessments to adopt. It has no doubt been reinvented hundreds of times; I first ran into it when I gave a seminar for the Scholar-Leader Enrichment Program at the University of Oklahoma. It was the minute paper concept that started me thinking about the broader definitions of assessment, in particular finding out where my students were conceptually before giving them an examination. [For more on the One-Minute Paper, see pages 156–157. –Ed.]

During class, my students will often work in groups. Every element of group work produces some kind of tangible product—a worksheet, observations, evaluations, or something—that counts for course credit. Were I to teach a small class, I might be able to grade these group products and give different groups different amounts of credit for what they do. Since my own classes are large, I simply give everyone participation credit for what they did. When it’s practical, I’ll ask students to evaluate each member’s contribution to the group—at midsemester for diagnostic purposes and at the end of the semester for part of their grade. (It is important to do the midsemester evaluation so that students who aren’t contributing to their groups can be given a chance to change their ways.) Instructors should make sure that raw student evaluations of their peers do not play too

large a role in overall course grades.

Halfway through the semester, my students in the laboratory are challenged to come up with their own investigation or Big Project. Students spend three weeks on their Big Projects, and then present them in a meeting of their laboratory section. They have tested detergents, mailed potato chips across the country in different packages, built toothpick bridges, and dropped carefully packaged eggs off seventeen-story buildings. Their presentations are evaluated on content and on communication skills (which need to be overtly taught). We have found that it helps to have someone other than their regular laboratory instructors judge their work. The highest-ranked projects are then presented to the campus community, along with projects from a biology course, in a poster session.

On the final examination, I include a variety of recall, reasoning, and higher-order thinking questions. There are the usual multiple-choice and true/false questions; in addition, students must draw conclusions from graphs and tables. I present them with concept maps, and they have to fill in the blank spaces. (If I had a small class, students would draw the concept maps themselves and I'd evaluate them.) Sometimes they have to write

essays, though I have found that giving them some questions ahead of time and having a few of those actually appear on the examination produces much more coherent answers.

Why use such a variety of assessments? What was wrong with the old way, with an hour exam or two and a final? The *National Science Education Standards* and other reform documents such as Project 2061 give a lot of reasons why multiple assessments are preferred. Two stick out in my mind as being particularly important. First, I want to make assessments that match the real world as much as possible in order to prepare students to tackle and solve problems they meet outside of class and in their later lives. Second, I learned some years ago that a teacher's tests define the real goal of the course for the students. If your syllabus contains a lot of words about developing critical thinking skills and your tests ask "What is X?", your students will quickly catch on that what really counts is memorizing vocabulary.

In summary, no single form of assessment provides me with an adequate picture of what students know—and understanding what students know is the key to better teaching.

Designing and Managing the Learning Environment



Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. In doing this, teachers

- Structure the time available so that students are able to engage in extended investigations.
- Create a setting for student work that is flexible and supportive of science inquiry.
- Ensure a safe working environment.
- Make the available science tools, materials, media, and technological resources accessible to students.
- Identify and use resources outside the school.
- Engage students in designing the learning environment.

Source: National Research Council. (1996) *National Science Education Standards*. Washington, DC: National Academy Press, 43.

Inquiry-based learning experiences often present logistical difficulties early in the assignment, as students form small groups and choose, within limits, topics to study. Many groups, for example, quickly face difficulties they are unprepared to resolve. Most problems stem from their ignorance of what physical quantity should be measured, or they may want to measure quantities their tools aren't designed to measure. However, designing a laboratory or field study forces the students to look more closely at their experimental design and the capabilities of their tools.

For faculty who are committed to providing inquiry experiences, new challenges of time, space, and resources arise.

Time: Often the hours of class time allocated to the projects are inadequate, and students (and instructors) must be willing, if necessary, to meet for additional hours to complete a project. Teacher oversight and guidance is necessary, and instructors spend considerable energy to keep the process going.

Space: Classrooms and laboratories are typically limited in their flexibility and tend to foster activities that are singular of purpose. In addition, space problems may arise when groups of students simultaneously differ in their experimental method and the materials they subsequently require.

Resources: Open-ended inquiry also poses the problem of finding available resources for students who choose their own topic to investigate. In some cases, the scope of an investigation is limited by the equipment available. Materials, too, may

not be available or may need to be acquired on short notice. This is in contrast to the direct instruction approach, which essentially requires chalk and a blackboard; for laboratory experiments designed to verify pre-specified concepts, a semester's worth of laboratory materials can usually be ordered in advance, since student behaviors and experiences are predictable. Inquiry-based learning produces unanticipated learning excitement—and unanticipated challenges of course management!

Limited time, space, and resources can pose unique barriers to the acquisition of scientific inquiry skills. Despite those management challenges, however, college science teachers believe the time spent to be worthwhile, as the following vignette demonstrates.

From the Field

Developing Experimental Design Skills of Students

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My experiences with inquiry teaching have met with mixed results. The first time I had students conduct their own investigations, I was pleasantly surprised. Small working groups were formed and everything proceeded smoothly. Students actually recommended including the inquiry-based project into the course structure, even though it required more work on their part.

My second experience was different. Of six working groups, only one group selected its own topic; the remaining groups chose from the instructor's list. The group that selected its own topic chose to investigate the magnetization of different materials. They made their own electromagnets, studied the characteristics of the magnetic fields produced, and then looked at how these fields were influenced by the introduction of different materials

into the core of the electromagnet. Their study brought them past the brief discussion of magnetic materials they received in their course work, and well beyond any experiences they had had in making and measuring magnetic fields. They developed ingenious ways to identify and quantify the changes in magnetic field.

Another (single-person) group looked at the effects of salinity concentrations on the conductivity of liquids. He planned and conducted his experiment with great care, using equipment borrowed from another department. Unfortunately, he exercised no flexibility in reshaping his experimental plan when his preliminary measurements led to unexpected results. Instead, he approached this project like any other laboratory exercise and missed the opportunity to pursue questions raised by his own work.

Two of the other groups had difficulty organizing any form of systematic investigation. With the instructor's assistance, both groups completed satisfactory investigations. The remaining two groups performed poorly. Both groups reached inaccurate conclusions by incorrectly interpreting poorly collected data. Their experimental design was feasible, but they ignored the need to keep some of the parameters constant while investigating the effect of changing others.

Why were these experiences so different? The second class seemed to be intimidated by the concept of an open-ended project. Most of this class did not share the enthusiasm of the previous class, and I found myself coaxing and sometimes pulling them along just to keep them working. Without strong intervention, I'm certain that two-thirds of these students would have foundered. The quality of the work completed by this class was, at best, mixed. What clearly emerged from these experiences is the inability of traditional laboratory exercises to prepare students for the study of real world physical systems. Without the guidelines provided in the traditional laboratory, students had great difficulty deciding what to measure and how to measure it. Even after deciding what parameter should be measured, they selected the wrong power supplies, chose multimeters when they really needed oscilloscopes, and made many other poor instrumentation choices.

How could this happen? Our students receive extensive instruction on

the content of our discipline. They have access to modern instrumentation and are thoroughly instructed on the rules of its use. Until my course, however, students had had no opportunity to use this knowledge to formulate and execute a study of their own. We have been so busy teaching science to our students that we failed to let them *do* science. We have failed to challenge our students with any relevant scientific problems to solve. When students are given the opportunity to study practical problems, the application of laboratory techniques and instrumentation that give unpredictable results force the students to think about their analytic and laboratory work at a level not encountered anywhere else in the curriculum. Even the undergraduates invited to work in our research laboratories are seldom given the opportunity to influence the direction of a research project.

From a practical perspective, I could not have predicted which students would most eagerly engage in the open-ended project. I observed one of our best students reduce the entire project to a thoughtless laboratory exercise, while some marginal students became very enthusiastic and imaginative investigators. Every group needed some guidance, but those groups that selected their own projects worked more independently than those that chose one from my list. While there may be several reasons for this, it's tempting to attribute the added enthusiasm to "ownership" in the project. From my experience, inquiry-based learning is much more effective

when a group selects its own project for study.

Finally, for most students the prospect of presenting an oral report of their work to their peers was more frightening than receiving a poor grade. Knowing they would have to defend their techniques and conclu-

sions imposed an unusual sense of thoroughness and honesty on their work. The presentations provided an excellent opportunity to practice communication skills; more importantly, they clearly illustrated the diverse ways that students tackled unique problems.

Building Learning Communities



Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers

- Display and demand respect for the diverse ideas, skills, and experiences of all students.
- Enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community.
- Nurture collaboration among students.
- Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.
- Model and emphasize the skills, attitudes, and values of scientific inquiry.

Source: National Research Council. (1996) *National Science Education Standards*. Washington, DC: National Academy Press, 45-46.

Two observations about life relate directly to Teaching Standard E: (1) Every individual is unique, and (2) living organisms interact with each other and with the environment.

Teaching Standard E emphasizes diversity and respect for individuals. In this context, educators at all levels should help students to identify and nurture their unique strengths as well as help them to identify weaknesses and work to overcome them. Of course, some might raise the following questions: If each individual has unique talents, then why should we encourage collaborations and learning communities? Shouldn't we encourage each unique student to learn independently? Is Teaching Standard E contradictory in this regard? The observation that living organisms interact with each other and their environment serves as an analogy for the learning community environment. Many different individuals working together can provide unique

insights and perspectives that extend beyond the thoughts of any single individual. Uniqueness of individuals does not disrupt the learning community environment—it enhances it. The instructor, who is the key to establishing the learning environment, should recognize individuality and encourage students to use collectively their unique talents to learn science.

The ideal college science classroom should be an interactive setting where students feel comfortable with the instructor, the teaching assistants, and with each other. All individuals should be readily exchanging thoughts about meaningful, interesting scientific concepts and issues, without fear of “saying something stupid.” The prevailing attitude should be one of respect for different ideas and a shared eagerness to learn more about the scientific topic. The most effective learning happens when students view the course experience as something special, of which they are all a part. If the instructor can generate and support such interactions and excitement, the stage is set for learning.

Although student input is important in the planning process, the instructor must take the lead. Asking students to help plan a course that they have never had seems unreasonable. The instructor should propose a framework, and then respond to appropriate input and modifications from students. Overall, such shared planning can provide the basis for the desired learning community. The following vignette illustrates many features that may be incorporated into a program to foster community.

From the Field

Creating a Learning Community in Introductory Biology

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Syracuse University

I have taught introductory college biology for more than forty-four years and have evolved mechanisms that seem relevant to Teaching Standard E. The introductory biology course is a two-semester course that serves both science majors and nonmajors. The course involves lectures, recitations, and laboratory work. I try to establish a learning environment where every individual feels important and comfortable. I constantly remind my students that each of them is unique and that my role as a teacher is to help them maximize

their individual talents and learning. I try to emphasize that my role is “to help you learn” and not to “fail you” or “get you” or separate the “geniuses from the dummies.” I would be delighted if my students all learned 90 percent of the content and received an A in the course. Indeed, I sometimes tell students some of the exact questions that will be on the exam (in modified form), and old exams are available for their review. Why should students have to guess what I think is important for them to know? Why can’t I tell them,

and then expect them to learn that content and do well on the exams and be rewarded? I often repeat questions (in modified form) that students had wrong on a previous exam, as bonus questions. Once students feel comfortable in class and have a good rapport with the teacher, they have an environment in which they feel free to learn as much as they can.

My course contains many diverse features that are designed to make it a unique set of experiences that extend beyond mere acquisition of content knowledge. I want my course to have a positive impact on students many years after they have completed it. Special course features include the following:

- *Bionews and Bioviews* (a weekly course newsletter)
- Bio-Lunches (lunch dates with small groups of students in the dining halls)
- *Bio-Answer Show* (a closed-circuit TV program during which I review answers to the exam and give away prizes in a drawing of student names from the bio-fishbowl)
- Support for taking examinations (e.g., review sessions before major exams; having old exams available in the library; bonus questions on exams [students love extra credit])
- Benefit-of-the-doubt credit (credit for students who attend extra sessions and lectures on campus—e.g., an optional Wednesday session [to enhance the content for the more interested students]; the Frontiers of Science Lecture Series [science faculty tell about their re-

search]; Pathways to Knowledge Lecture Series [Ph.D. students present their research])

- Bio-Creativity contest (students create something about “life”—e.g., a poster, poem, essay, or model—and receive ten, five, or two points toward their final grade)
- A cooperative research project on plants
- A pig dissection, followed by a “pig interview” with a teaching assistant (nobody leaves the course without a one-on-one consultation with an instructor)
- Support for self-learning (e.g., audiotapes, CD-ROMs, demonstrations, models, videotapes)

These special features are intended to create a sense of excitement, so that students feel proud that they are a part of a set of unusual experiences designed to help them learn.

The laboratory is open seven days a week (including nights) to help students learn to manage their own time. A teaching assistant is always available, and students are encouraged to drop in to do laboratory work whenever they have the urge to do so. I want students to talk to each other and to teaching assistants, so the laboratory becomes a social environment where students learn from and interact with each other.

Although Teaching Standard E emphasizes the importance of nurturing collaboration among students, this may not be desirable for all individuals. Some students do not want to

work in groups on a research project or a dissection. Should we force such students to work collaboratively? I think not. I try to encourage students to collaborate, but I respect the individuality of a student who wants to work alone, and such students can do so in my course.

In general, we should try to use our course experience to meet the needs and interests of students, be partners in the learning process, create an exciting learning environment, and help students to learn in such a way that the course is still having an impact on their lives twenty years later.

Participating in Program Development



Teachers of science actively participate in the ongoing planning and development of the school science program. In doing this, teachers

- Plan and develop the school science program.
- Participate in decisions concerning the allocation of time and other resources to the science program.
- Participate fully in planning and implementing professional growth and development strategies for themselves and their colleagues.

Source: National Research Council. (1996) *National Science Education Standards*. Washington, DC: National Academy Press, 51.

Although Teaching Standard F is written for K–12 science teachers and addresses school science programs, it is pertinent to university and college teachers of science with slight adaptation. The Standard notes that K–12 science teachers should participate in program development in their departments and their institutions with careful attention to Teaching Standards A through E. To accomplish this on the college level, science teaching faculty should first understand the conceptual basis of national, state, and local initiatives of science reform; then, they can put the initiatives into practice. Thus, in all teaching, science faculty should strive to

- connect science concepts to real world issues relevant to the lives of students;
- actively engage in ongoing program development and assessment to meet changing needs of student populations;
- collaborate and network with other colleges, departments, school systems, informal science centers, and the public and private sectors during the process of program development; and
- foster a vision of scientific literacy that encourages practical knowledge of the nature of science, developing habits of mind consistent with positive scientific perspectives and attitudes, stressing skepticism and critical thinking, teaching

for conceptual understanding of seminal linking themes and theories among the sciences, embedding science in cultural and historical contexts, and providing opportunities for students to generate their own meaningful questions and design approaches to investigate real world issues.

Teaching Standard F may be considered somewhat of a double-edged sword. On one edge, the Standard appears to be an obvious statement that the K–16 (and beyond) teacher of science would assent to: that science teachers should exercise both their academic freedom and content knowledge expertise in the planning and development of new science curricula. The need to update existing science courses or formulate new courses based on current research relevant to a field of study has been a historic and continuing concern in college science teaching. Despite the perennial “updating” of course material, however, very little else seems to change in higher education in terms of the design and delivery of most foundation science courses. But the opposite edge of the sword suggests another way to think about such program development: from a bottom-up, interdisciplinary, global perspective. Change for the sake of change is probably benign at best, and foolhardy at worst. But change in response to recent research about how students construct knowledge, seek relationships in nature, and demand to know how science is relevant is imperative; and change in response to how students will negotiate their lives through a maze of real world issues and problems is, at the very least, prudent.

College and university science teachers and science educators are in a unique position to engage in curriculum reform that reflects national K–12 science education reform initiatives. To make an informed decision about the extent to which one wishes to participate in program development and restructuring, higher education science faculty must make a concerted effort to understand the visions of future scientific literacy, the thematic strands that permeate science, the ways in which students learn science, science’s connections to other disciplines, multiple forms of assessment, and ongoing program evaluation efforts. Rethinking logistical arrangements of course delivery (e.g., scheduling that allows more time to pursue small-group collaborative research projects, working with mentors, shadowing professional scientists, developing partnerships with industry) is now a viable option. Although being involved in such rethinking is not a simple undertaking, it does represent a full expression of academic freedom and empowerment by university science instructors who want to affect their students’ lives through a systemic approach to program development.

From the Field**Aligning Courses for Standards-Based Teaching**

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Recently I was offered an opportunity to develop an introductory science course that would bear little resemblance to traditional courses for nonscience majors (which could count as an elective for science majors). A colleague in the Department of Biology at the University of South Florida where I teach asked if I might be interested (as a science educator) in ferreting out seed money to create a new course for the College of Arts and Sciences that was consistent with the common themes of national science reform initiatives.

Here was an opportunity not only to talk the (reform) talk but to walk the walk. As we discussed ideas a bit further, we identified a small agency through NASA/NOVA that would fund teams of faculty and administrators who wished to either modify an existing course or develop a new course that echoed the science reform initiatives (and incorporate some of the goals of NASA as well). It was preferable that such teams consist of a science or mathematics educator, a faculty member from a science discipline, and an administrator (e.g., faculty chair, associate dean, dean) from the university. We found our third partner in the form of an associate dean—also a member of the Department of Biology—who shared our interests in devel-

oping alternative courses that would better engage students in scientific thinking and discourse. Putting together such a collaborative team would prove to be imperative in weakening the rigid college boundaries and personal niches that traditionally exist within many university structures.

As our team shared knowledge of local, university, state, and national resources with each other, a link between an aging population and the space industry seemed natural to us. A preservice science education/general education course (taught out of a science department) that incorporated the elements of long-distance and longtime space travel, the use of aging astronauts in space research, and natural developmental and aging processes on Earth would, we concluded, have broad appeal and relevance to future teachers and citizens in Florida. And so our team members collaborated with each other, sharing content and pedagogical knowledge, and directed our efforts in the “selling” of this new course to the College of Arts and Sciences and the College of Education by using the national science reform documents as our guide. Our emphasis was on systems, models, constancy and change, and scale. The decision by NASA to send John Glenn back into space reaffirmed a long neglected

idea for us—that age has value. Furthermore, the need for long-term endurance as we travel increasingly farther from Earth emphasizes the need to understand better the aging process. From this premise, a new course emerged: Space Age Biology.

We think that a course about the concerns and challenges of long-range space travel and the normal problems of a senior citizen functioning in space will enable us to focus also on the biology of aging on Earth. Consider the following examples:

- A potentially lackluster unit on energy flow, metabolism, and respiration is enlivened and enriched by discussions and activities that focus on survival in a self-contained closed system such as the International Space Station. We include an activity in which our heterogeneous students (mixed ages) create a plan for spending a week together in a room the size of the living quarters of the space station. Respiration, nutrition, excretion, exercise, and entertainment have to be managed, along with the unique needs of seniors.
- A discussion on the genetic limits of aging and the relationship of life span to metabolic rates is related to time limitations in space, modifications of metabolic rates, and the possible use of technology to extend life spans. Birds are famously long-lived yet have very high metabolic rates—a seemingly inherent contradiction. Why? Scientists have recently re-implanted

modified drosophila genes in fruit flies and managed to increase their lives by 40 percent! Students may design small-scale projects involving metabolism and/or genetics for future consideration by NASA scientists.

Examples such as these illustrate how students are engaged through topics meaningful to their lives. NASA data will stimulate their thinking, and through their own designed experiences and problem-solving challenges, they will, one hopes, apply the science concepts in ways that will improve and extend their lives.

Our efforts to seek new pathways to participate in program development have stemmed from the common pedagogical themes that are woven throughout all of the national science reform initiatives. Our team will continue to develop and implement several of the most pervasive themes that recommend fundamental changes in how we teach science. The most important of these themes include the practice of:

- constructivist-based understanding of learning;
- hands-on/minds-on, active, problem-solving investigations;
- emphasizing the interdisciplinary connections of science and the history and nature of science;
- relating science to the students' world;
- consideration of personal, social, and ethical issues;
- focusing on fewer science topics in more depth;

- full integration of appropriate technology in instruction;
- teachers being facilitators of learning and learners as well;
- cooperative learning situations;
- science as argument and explanations; and
- multiple (alternative, in conjunction with traditional) forms of assessment.

If we believe that higher education must ensure scientific literacy for all of our students, then elements of these themes must be present throughout our curriculum. And if we are willing to invest our energies in collaborative program development, then the paths we choose are more likely to be responsive to the national reform initiatives and the changing needs of our students.

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