The College Board
Science Framework

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Preface

The College Board's mission is to connect students to college success and opportunity. Our focus is on improving students' academic preparation for college by creating products and services designed on the principled assumption that all students can learn and achieve high academic standards. Research tells us that high standards—statements that clearly articulate what students should know and be able to do within science—together with high expectations for all students and strong teacher professional development, optimize student learning.

In keeping with the College Board's tradition of conceptualizing goals and best practices in American education, and of implementing them in its various programs, this Science Framework provides a common language and structure for designing curricula, instructional materials, assessments, and professional development efforts. Frameworks articulate the philosophy and guiding principles for creating the integrated product set, that is, enhanced standards, instructional materials, assessments, and professional development, we envision for the College Board's K-12 development initiative. The educational philosophy is founded on the principles of academic excellence and equity. Indeed, here we make the case that equity without excellence is folly. Frameworks elaborate a simple central idea—that integration of instruction, assessment and professional development is a powerful tool for improving student achievement. These frameworks are intended to guide those charged with creating instructional materials, designing appropriate assessments, and implementing professional development.

The primary benefit of constructing and validating a design framework for the Grade 6-12 development effort is improved student learning predicated on high quality instructional design and integrated student assessment.

Creating frameworks for the development of courses also has a number of other benefits.

- A framework provides a common language for discussing the knowledge, skills and abilities to be taught and measured in these instructional activities.
- Such a discussion allows us to create a consensus around the course framework and measurement goals—it takes the mystery out of what is taught and what is tested.
- A careful analysis of the complimentary sets of knowledge, skills and abilities underlying successful performance in these courses—the habits of mind, if you will—provides a basis for creating standards or levels of proficiency to guide course design.
- Identifying and understanding particular variables that underlie successful learning and performance furthers our ability to evaluate what is taught and what is learned, and influences the design of our measurements.
- As we increase our understanding of what is taught and how this content fits with agreed upon standards of learning our ability to design instructional activities and materials, prepare teachers, and develop and score assessments that are integrated is enhanced. This, in turn, creates a conceptual framework for promoting the product line—making communications about these offerings richer and more informative.

Guiding Principles

With the publication *Learning and Understanding*,[1] the National Research Council's panel carefully detailed what learning with understanding means in a school setting. The publication details seven principles, drawn from research, that summarize quality learning.

1. Learning with understanding is facilitated when new and existing knowledge is structured around the major concepts and principles of a discipline.
2. Learners use what they already know to construct new understandings.
3. Learning is facilitated by use of metacognitive, or reflective, strategies that assist learners in identifying, monitoring, and regulating their cognitive processes.
4. Learners have different strategies, approaches, patterns of developed abilities, and learning styles because of interactions between their opportunities to learn and their prior experiences.
5. Learning is situated in activity and is shaped by the context and culture in which it occurs.
6. Learners' motivation to learn and their sense of self affect what they learn, how much they learn, and how much effort they will put into the learning.
7. Learning is enhanced through socially supported interactions.

These principles inform and guide the following five areas that are considered relevant to the development of the science learning: *equity and excellence*, *standards*, *curriculum design*, *assessment* and *professional development*. The first of these, Equity and Excellence, is necessary for successful implementation of the other four areas in order to achieve scientific literacy for all students.

Equity and Excellence

The issue of Equity and Excellence must play a central role in K-12 science instruction reform. Equity in science demands that all students have equal access to rigorous science courses and programs. This means that students who have been historically under-represented in and traditionally discouraged from the sciences, minorities, women and rural groups, must be encouraged and have equal access to meaningful science programs. These programs should be based on the principle that all students can and will learn science. As such, science programs should be crafted in ways that ensure (1) Programs meet the particular needs of students and are appropriate to the teaching/learning process, and (2) that the nature of the environment and diversity of students are considered. This approach will have the effect of providing the framework for meaningful assessments and evaluation to see that all students have an equal opportunity to achieve.

The national effort to establish clear and rigorous standards for the country's K-12 science programs is now well established. A major goal of this effort is to create a scientifically literate populace to meet the challenges of the 21st century. An equally important goal is to provide the opportunity for all students to be prepared for post-secondary science courses. Both of these goals require not just ensuring rigorous standards-based curricula, but also a set of committed objectives that result in fair and equal access with high expectations that will improve the participation and achievement of all students regardless of sex, race and socio-economic status. The implementation of the Federal government's No Child Left Behind Act seeks to improve or reinforce the state standards and thereby raise the level of science instruction and accountability for the whole nation. However, to have meaningful and lasting progress in science achievement among our nation's children, a concomitant effort aimed at ensuring equity and excellence must be embarked upon to achieve the goals of improved science learning.

The development of a comprehensive science framework by the College Board builds upon and complements nationally recognized standards for science such as Project 2061 (Benchmarks for Science Literacy)[2] and the National Science Education Standards[3]. These efforts help in the achievement of excellence in science education for all students, impacting curriculum and assessment. As such, this framework emphasizing rigor and high expectations ensures that the K-12 science experience of students will facilitate their understanding of new and existing knowledge structured around the major concepts and principles of the discipline. Such an approach will create excitement in science learning and teaching across the 6-12 grade level.

Successful teaching and learning are intertwined, especially so in the field of science. Therefore, to assure excellence in student learning in the sciences, professional development programs for teachers based upon research and best practices should be encouraged. These programs should be tailored to fit existing local districts and their special circumstances and include the expertise of higher education science professionals. In this way all students are served based upon their existing need and it is ensured that they receive the same high level of instructional excellence.

Achieving both equity and excellence in expectations is not an easy task. Such coordination includes a vertically aligned curriculum, consistent high levels of expectation, and sustained communication among teachers, councilors, administrators, parents and students. These efforts include building a solid base for science in the primary grades and ensuring appropriate experiences throughout the middle and secondary grades. Secondary and K–8 staffs will assist one another to help all students reach their potential. The goal is to create rigorous curricula that meet or exceed the recognized standards, and to provide instructional strategies and support that give all students the opportunity to achieve excellence in these high-quality programs. Such support may include one-on-one and small group tutoring, walk-in assistance centers, technological aides, and special motivational efforts. We believe schools should strive to provide students with instructional role models and community support that reflect the notions that all students can be successful and that science is important in their lives. Establishing an ongoing professional development program for school faculty is important to this effort. Professional development involves growth, both in the knowledge of science content and in how it is best taught at different grade levels. As part of this effort, teachers may gain knowledge of students' backgrounds and cultural traditions and understand how to use that knowledge to enhance their success in school science.[4,5,6]

Standards

The national policy to improve the state of science education at the K-12 level has led nearly every State in the union to develop standards for the teaching and learning of science. These standards are based either on the individual states' criteria or are informed by the national standards[2,3].

Standards provide a set of guidelines that inform what every child should know and be able to do in science at every grade level. In most instances, standards represent the minimum that students are required to know. State and National efforts do not address how minimum competencies can be achieved. Many do not address issues of teacher professional development.

Schools must utilize national or state standards for vertical articulation of process and habits of mind in grades 6 through 12. However, teachers must incorporate rigorous curricula that exceed the recognized content standards to ensure understanding and achievement in each science discipline. An integrated standards-based approach to the teaching and learning of science in grades 6-12 is intended to ensure that all students experience a rigorous research-based science curriculum that prepares students for post-secondary science courses, including Advanced Placement curricula.

Curriculum Design

Recent cognitive research into "how knowledge is organized, how experience shapes understanding, how people monitor their own understanding, how learners differ from one another, and how people acquire expertise"[1] reinforces the need for "learning with understanding." Learning with understanding is achieved when knowledge is absorbed and experienced in ways that also clarify how it can be used. The concept of "learning with understanding" acts as a lens under which to examine and to redesign curriculum, instruction, assessment, and professional development. To achieve successful learning with understanding, all science classrooms should adhere to the seven fundamental guiding principles presented in the preface, drawn from research, from the NRC's report *Learning and Understanding*.[1]

While cognitive research has yielded new learning insights for decades, the implications for curriculum and assessment, as well as for professional development, have not always found their way into classrooms. These principles should guide the selection of content, the choices of assessments, and the professional development of teachers. The guiding principles say a great deal about how content might be selected and structured for a curricular framework, as well as about how to introduce such content to students.

From a design perspective, materials for either students or teachers should:

- Use unifying concepts, principles, procedures, and representations as the central foci in the development of lessons, delivery suggestions for instruction, and selection of assessment strategies.
- Design knowledge-centered and learner-centered science classes organized around core concepts and activities that facilitate the mastery of subject matter.[7]
- Strengthen understanding of new concepts by assessing and building on students' prior knowledge, showing the links and relationships between the two.
- Incorporate more active, investigative and inquiry-based teaching and learning in classroom lessons, laboratory and field work.
- Recognize individual learning styles by presenting content in a variety of representational modes.
- Reflect learning with understanding and transfer—the ability to extend what has been learned in one context to new contexts[8] using a variety of representations, such as graphical, symbolic, verbal or pictorial, in course and assessment design.
- Include activities that foster students' capabilities to reflect on and guide their own work in all forms of assessment (metacognition).
- Integrate different problem solving, reasoning and conceptual questioning strategies that help students approach new situations with a focus on learning.
- Foster group approaches to learning and solving problems, in addition to individual approaches. Students must

experience science as a collaborative effort as well as an individual one.

- Recognize different cultures' perspectives and contributions in an attempt to relate science to students' racial and ethnic origins, as well as to examine prevalent applications of science in learners' communities or careers involving students' parents.
- Create a clear sense of the value of science in students' lives and a confidence in each learner that he can "do" science. Students should develop an increasing respect for and command of science, both as a discipline and as an approach for solving problems in their everyday lives.
- Promote an understanding and appreciation of the historical developments of key ideas in science and of connections to other disciplines in the study of science.
- Enable a student to develop the skills to participate in group discussions on scientific topics, to restate and summarize accurately what others say, to ask for clarification or elaboration, and to express alternative positions.
- Enable a student to describe, in words, an experiment or derivation he or she has done to an audience of non-experts, avoiding jargon and following a clear logical path between question, method, solution, and impact.

Five major considerations should be given to curriculum design that utilizes these recommendations: *Role of Unifying Concepts, Depth vs. Breadth, Role of Prior Knowledge, Laboratories and Fieldwork* and *Inter-disciplinary Connections*.

Role of Unifying Concepts

Instructional programs in the sciences must feature unifying concepts and themes that connect the central ideas of the discipline. It is only through the identification of unifying concepts or themes that students see the connections between biology, chemistry, physics, and earth science. Since there is both a hierarchy as well as a cyclical nature to learning and understanding the sciences, it is imperative that the connections be made to bring the ideas together for students through their years of studying the discipline.

The unifying theme of science as a process with relevant connections to students' lives and current knowledge in other disciplines should be woven throughout the framework and provide context for understanding the relevance of how science is done.

Depth vs. Breadth

The development of a deep and well-integrated understanding of fundamental scientific concepts is essential to the success of any science course. Within the framework of a progressive yearlong course, students will need to reinforce and revisit core concepts such as energy transfer through a breadth of interrelated ideas and facts. This approach will continue to provide a firm foundation for students to learn and understand more advanced concepts. When depth of understanding is emphasized and concepts are properly linked students will be equipped to navigate complex and diverse content and to interpret and transfer their knowledge during assessments.

A "less is more" principle or the notion that it is better to "uncover material than to cover it," should guide the careful selection of content that will best represent and reinforce a depth of understanding of these core concepts.

An understanding of the process of science and the hierarchy of interrelationships among theories, principles, concepts and facts should also be reflected in the assessment design. As a result, each student, regardless of the instructor's unique approach, should be assessed on the same concepts with less emphasis on memorizing and retaining superficial and unrelated facts, and greater emphasis on the ability to think independently about the relationship of ideas and of science as a process.

Role of Prior Knowledge

Key in the usefulness of a science framework is the building of concepts and processes on a foundation of years of scientific study. Along with the development of scientific understanding should be quantitative understanding (the ability to reason with numerical and logical information including graphs and charts).[9] A degree of scientific literacy and competent reading and comprehension skills at the appropriate level will also play an important role in prior knowledge expectations.

An accrued, common body of prior knowledge and skills in natural and physical sciences and mathematics, and an understanding of the relationship between science and society and science and humanities will allow teachers and students more time in class, at home, and in laboratories to advance their learning and understanding of abstract concepts. Mathematics and science courses are subjects initially built layer by layer—though it is also worth noting that knowledge may be built sideways, downwards and through multiple pathways. Thus, it is expected that study of high school science courses will ultimately affect preparation at the elementary and middle school levels where students build firm foundations essential for high school and college-level courses. While it will require a strong commitment for schools to strengthen and enhance their total curriculum, it will also be important to reiterate that support and encouragement will be available to schools and teachers from a variety of school districts, including those traditionally underserved.

Laboratories and fieldwork

Active, inquiry-based laboratory and fieldwork is essential to learning and understanding science. "Science process centers on direct interactions with the natural world aimed at explaining natural phenomena. Science education would not be about science if it did not include opportunities for students to learn about both the process and the content of science."[10] The College Board should therefore ensure that teachers are qualified to teach laboratories throughout the entire school year and that students of all ages have the proper resources and time to conduct them both inside and outside the classroom. Current guidelines for laboratory and fieldwork include the following:

- A required minimum amount of class time dedicated to laboratory and/or fieldwork.
- Laboratory curricula that range from skill-based to open-ended investigations emphasizing not only what "works" in the lab and field, but also the process of scientific research including why some experiments yield unexpected results, and how those results lead to further insight.
- An emphasis on science literacy, information literacy, and science, technology and society within the context of laboratory and fieldwork studies.
- Integrated instructional units that connect laboratory experiences with other science learning activities including lectures, reading and discussion.
- Ongoing support and training, provided by the College Board, to prepare teachers at all levels for laboratory investigations.

When students experience the process of inquiry firsthand, knowledge becomes more relevant and meaningful. Students learn about their own abilities to learn as they discover "what counts as evidence, what kinds of arguments are compelling, what kinds of knowledge can result from investigations, and how such knowledge can help understand other contexts and social issues."[11] Educational research also indicates that laboratory and fieldwork helps diverse groups of students improve their mastery of subject matter, develop scientific reasoning, and enhance their interest in science.

Active and inquiry-based work encourages problem posing, problem solving, and peer persuasion. When students learn and process new information through active discovery, they are more engaged in both thinking at a higher level and in exploring their own attitudes and values. Furthermore, students will not understand how scientists think until they are given the opportunity to experience science from practical, laboratory and field approaches to learning. Understanding how scientific knowledge is created, changed and practiced promotes an understanding of the potential, as well as the limits, of science.

In addition to laboratory experiments with predicted strategies and outcomes, open-ended laboratories are essential to:

- understanding the process of doing science;
- understanding and describing a problem;
- assessing prior knowledge and dispelling misconceptions;
- learning and sharing ideas in a group setting; and
- learning to think independently both in cooperative settings and in the process of assessing laboratory results in written reports.

Interdisciplinary connections

The College Board recommends making connections across traditional disciplinary boundaries when teaching science, with an emphasis on scientific literacy and quantitative reasoning. Interdisciplinary connections remain critical in the learning and understanding of all of the sciences. It is also important, where appropriate, for teachers to highlight, stress, and clarify ways that each of the sciences, as a discipline, has been influenced by thought and intellectual development in the broader spectrum of the liberal arts and other sciences.

Students have to experience learning activities that teach them about interactions among the sciences, mathematics and human-designed technologies in modern scientific problem solving. Further, students need to understand the historical, political, and social links between science and society at large. This framework for the sciences promotes an interdisciplinary approach to navigating content both within and between varied disciplines, and provides an important context for a deeper understanding of the sciences and their relationship to society at large.

Contemporary examples of how modern science affects social, economic, and government policies and decision-making are also important to an interdisciplinary classroom experience. Student learning is enhanced when concepts are taught within the context of their everyday lives and contemporary events and issues. Historic examples and case studies play a valuable role in promoting an understanding of the nature of science, and in introducing students to significant Western and non-Western contributions to scientific progress.

Assessment

Background

In the vision described by the National Science Education Standards, assessments are the primary feedback mechanism in the science education system. They provide students with feedback on how well they are meeting expectations, teachers with feedback on how well their students are learning, school districts with feedback on the effectiveness of their teachers and programs, and policy-makers with feedback on how well policies are working. This feedback in turn stimulates changes in policy, guides the professional development of teachers, and encourages students to improve their understanding of science. Assessments must be developmentally appropriate, set in contexts familiar to students, and as free from bias as possible. At the district, state and national levels, assessments need to involve teachers in their design and administration.

Assessment and evaluation activities associated with College Board programs in science education offer to teachers and other school personnel a vision of how to collect and use information to improve learning and instruction and to accurately describe students' developed knowledge and abilities to use it productively. Score reporting is well-designed to address the needs of the students, teachers, and institutions.

Ideas about assessments have undergone important changes. As content and process goals and instructional approaches change, assessment methods must also change in order to keep these components aligned. Historically, the collection of data about student learning has been separated into classroom and external evaluations. The former were mainly directed toward giving the student a grade and the latter were used to place a student or certify a student's performance. Little attention was given to developing techniques for collecting information for instructional decision making in real-time. Most of the uses of evaluation were focused on summarizing and reporting the outcomes for some unit of classroom work. Most have paid some attention to the modes used in the design and delivery of the required state examinations where they exist. However, much less emphasis has been placed on developing modes of assessing students as part of the regular delivery of instruction in the classroom.

In the newest view, assessment and learning are two sides of the same coin. Assessments provide an operational definition of standards, in that they define in measurable terms what teachers should teach and students should learn. When students engage in assessments, they should learn from those assessments. Assessments should lead to a rigorous understanding of learning objectives and should be designed to fit naturally into courses to support the students' learning process. Assessments have become more sophisticated and varied as they have focused more on higher-order skills. Probing for understanding, reasoning, and use of that knowledge are developed through inquiry. A challenge for teachers is to effectively evaluate this type of classroom learning. Assessments should be considered a vital component of the design for a best practice course.

Laboratory work is a necessary part of each science course, and should be assessed. Laboratory work should encourage the development of important skills, such as detailed observation, accurate recording, experimental design, manual manipulation of equipment, data interpretation, statistical analysis, and operation of technical equipment. Laboratory assignments offer the opportunity for students to learn about problem-solving, the scientific method, the techniques of research, and the use of scientific literature. Student-generated laboratory reports encourage higher-order thinking as students process data, interpret results, collaborate with peers and design other possible experiments. Teachers may assess students not only by written lab reports but may include evaluation and monitoring of student progress through investigation, generating ideas, and formulating inquiry through experimental design. In order to assess the degree to which students are able to process data, make connections, solve problems and communicate clearly, there must be a complete assessment of student work. Samples of student work should include coherent explanations that describe their thinking, their solutions, and the answers or decisions required by the problem posed.

Both formative assessments (ongoing during the year) and a summative (end-of-course) assessments must occur in the evaluation process and must vary in complexity. A dual assessment consciously transforms instruction by providing critical feedback to teachers about student learning. Consequently, new assessment methods not only result in updated and improved measurements of learning and understanding, they improve the classroom experience.

Assessment instruments should:

- Provide opportunities for students to apply concepts to unfamiliar situations and to synthesize ideas or interpret patterns from experimental data.
- Accommodate a contemporary understanding of how students learn.
- Include emphasis on concept driven versus fact-based teaching and learning methods.
- Use active, inquiry-based scientific investigation and problem solving.
- Include appropriate laboratory and quantitative skills.
- Incorporate interdisciplinary connections where relevant.

Strategies for Assessment

Assessment activities might include pre-class assignments to determine prior understanding, discussions or performances during class, homework, lab notebooks, portfolios, interviews, investigative reports, class presentations, oral examinations, written essays as well as traditional paper and pencil tests. Portfolio and performance assessments are likely the least familiar of these methods.

Portfolios:

One of a variety of formative assessment tools is the use of portfolios as a method of evaluating and assessing learning and understanding. Examples of approaches to formative portfolio assessments could include:

- An information portfolio designed to document acquisition of conceptual knowledge. For example, understanding readings and developing problem-solving abilities.
- A skills portfolio designed to assess lab work, case studies, and/or computer simulations.
- A contextual knowledge portfolio designed to assess contextual understanding of science in society. This may include historical science readings and current readings in the popular science press. It could also reflect accumulated knowledge of course content and thus be presented as a summative, capstone portfolio.

Performance assessment:

Newer forms of assessment require students to engage in reflective thought in responding to tasks in both formative and summative assessment settings. These assessments provide teachers with evidence of student work that helps diagnose difficulties students may be experiencing. Teachers should know how to detect and correct misconceptions and observe the development of students' reasoning, use of representations, communication, and problem-solving skills using student-centered constructed-response items. These are sometimes referred to as "performance assessment," "situational testing," "authentic assessment," or "assessment in context." Teachers will require more time to evaluate these assessments. However, using this format will enable students to demonstrate their own thinking and approaches to addressing and solving problems and communicating their answers.

Teachers need to learn how to use *grading rubrics* and how to merge information from a variety of assessments into a final summative evaluation of a student's work. Teachers need experience in employing rubrics in ways that ensure students' work is scored in reliable and time-efficient ways. Such approaches to measuring student performance and using results to improve student learning also require giving students opportunities to learn characteristics of good responses on such assessments. It means that students should have non-graded classroom experiences to understand the expectations of tasks on these new assessments. One way to do this is to engage students in designing rubrics and in grading a series of papers themselves. Focusing on new approaches without concern for developing students' capability to function in new learning environments will not move student learning forward, it will simply perpetuate the same type of student responses—those focused at the replication and memorization level.

There should be *strong links between classroom assessment*, *appropriate instruction*, and high-quality student learning. When these are aligned, fear of assessment diminishes, focus on instruction increases, and high-quality education takes place. When the political processes associated with high-stakes assessments begin to match the desired and taught outcomes of a high-quality curriculum, the gap between students passing the test and students who can actually perform the tasks when they enter college disappears. As summative assessments are used to better inform the instructional process while doing what they are designed to do, the match between classroom assessment and instruction will improve. The focus on high-quality curriculum, instruction, and assessments is a long-standing College Board objective.

One method for achieving this goal is collaboration with members of a vertical team. Working with a team allows for a progression in the development and sophistication of test-taking skills. A cohesive science vertical team can implement strategies to ensure that students have sufficient exposure and opportunities to master these skills. As a variety of assessment strategies are utilized in K-12, summative assessments such as the AP exams should be accessible for all students regardless of race, sex or socioeconomic background.

While formative and summative assessments are required, some attention should also be given to assessing students' attitudes toward and beliefs about science as they move through K-12 into life beyond high school. A scientifically literate population is a key goal of the science frameworks.

Professional Development

Professional development is central to student success in the sciences. Deeper, more meaningful and resilient levels of student understanding will not be achieved without attention to the preparation of the teachers charged with teaching not just the AP courses, but all courses designed to prepare students to succeed in college-level science. This will require equipping teachers with new content and pedagogical methods by offering ongoing workshops and support of teacher/peer support groups throughout the school year. Research shows that sustained professional development is essential.[12] The science of learning has taught us that teachers affect their students' ability to learn with understanding by employing specific instructional strategies. Laboratory and fieldwork, small group discussions, lab reporting and writing, and concept mapping are just a few examples of strategies that provide both teachers and students the opportunity to exchange ideas and to correct misconceptions.

Teachers directly interact with students and make decisions about topics, materials, instructional approaches, and assessment of student learning. As such, who they are, what they know, what they do, where and why they do what they do, and what support they receive in their efforts are critical considerations in any plan for strengthening and improving the teaching of science. Teachers ultimately have the power to do it well, to make the decisions that create opportunities for all students to learn science.

Historically, the professional development of teachers of science followed an additive model in which teachers attended workshops to learn about topic X or did a short course aimed at developing pedagogical skills related to teaching method Y. The vision held was one of adding components to the teacher's initial teacher preparation experiences. However, the systemic nature of the relationships between content, learning, curriculum and instruction, and the nature of the changes needed in each, requires, in essence, a paradigm shift[13]. For professional development opportunities to provide maximum benefit, they must grow from the occasional, one-time professional development package to a new and more comprehensive model of sustained relevant and timely interaction in a setting that is both familiar and challenging. The setting should be composed of teachers at several levels of expertise in science content and teaching methodology all working together to raise the quality of instruction for all students.

Building Communities of Practice

Schools, teacher education programs, and professional associations involved with science education have all had a conception of professional development as something they "delivered" to teachers. This enhanced model of professional development has been conceived of as emerging, to a great degree, from communities of teachers and professional developers working together to know the science they teach, the habits of learners, appropriate pedagogies, and assessment strategies, all in the context in which they teach. If teaching is to improve, change has to start at the school level in science faculties. Change will incorporate activities that reach beyond the individual teacher to activities that alter the practice of a staff, then the practice of a district and, finally, the practice of a profession[14].

To make a lasting change, the formation of effective patterns of professional development must aid the profession in examining:

- Changes in the content to be taught and what it means to know the content well enough to teach it;
- The nature of learning and how conceptions of learning interact with pedagogical methods;
- The notion of what teaching means in contemporary schooling;
- What it means for a child to know and be able to do something in science; and
- What it means to be a professional science teacher.

Any plan that proposes to assist teachers in changing their teaching of science ought to provide a basis for the continued development of teachers' content knowledge and pedagogical skills and the relationship between content and pedagogy. Such efforts at dealing with teachers' conceptions of content will recognize that knowing science and knowing how to teach science are two different things. Teachers also need an understanding that is more global, one that deals with how the present content fits into the rest of school science and mathematics, what its long-term importance is, and what the value of this content is to the students.

Focusing on Constructing Content

Central to teachers' understanding is their ability to represent content in a variety of ways and, more importantly, their need to know which representations (verbal, graphical or symbolic) are most appropriate for a given learner and concept at a given point in time.

Teachers must have the opportunity to discuss, reflect upon, and practice classroom methodologies that are based on and consistent with research in best practices in learning. As teachers work with the content and processes relevant to their curriculum they need to ask questions such as: What do we know about the linking of teacher evaluation and student learning of science? How do middle school and high school students process connections between science content and that of other disciplines within the larger context of the real world? What misconceptions do students have, and how are they manifested in students' work? Where does technology, such as electronic data collection, fit into developing students' capabilities to form deductive arguments? How effective are available software applications in the analysis of data from real-world contexts? What beliefs do students have about science as a discipline and about roles that science plays in social and governmental affairs? What are students' beliefs about their own capabilities relative to science and scientific problem solving? What role models do students have for the study of science from those inside and outside the "scientific community"? How can teachers best prepare and inspire students to be life-long learners of science? As teachers plan for working with their students, they need to carefully consider these and similar questions. Their answers will guide, frame, and focus ways in which they approach designing meaningful instructional plans and creating valuable learning experiences for their students.

Link to Learning

In a like manner, professional development programs should be grounded in practice with an eye toward student learning. Teachers both desire and deserve to see how the science education principles presented in such programs will play out in a classroom setting. This is one reason why professional development programs should be structured around teachers teaching, and learning with, other teachers. The development of communities of practice where teachers share with one another and eventually begin to plan with one another is a cornerstone of educational practice in many Asian societies[15]. As teachers gather on a yearly basis to evaluate students' work on AP examinations, they exchange ideas on instruction and expectations. Throughout the year, many of these teachers stay in contact via meetings, institutes, workshops, e-mail, and other forms of communication. These communities have grown into strong bodies fostering exemplary science education practice in the U.S. The network of teachers shares lessons, projects, and teaching strategies via the Internet and at regional and national meetings for teachers. If real, lasting, and self-replicating change is to occur, such networks must be fostered and supported and expanded to include science teachers at all levels[16].

Not only should professional development opportunities for science teachers be directed at the practice of contemporary programs in the discipline, but they should also occur in settings where teachers have an opportunity to practice instructional strategies and receive feedback on them in real time. Professional development programs that never extend beyond theoretical models for instruction do little to further capabilities of teachers involved. Those professional development programs that are clearly connected to the classroom, that model appropriate classroom teaching practices, and that result in significant increases of student learning will clearly be more effective than those that do not [17,18]. Teachers need an opportunity to take an active role in trying out various approaches and to have a chance to recycle their attempts, to hone their practice with new methods of teaching and assessing [13]. At the same time, the public and professional leaders cannot expect changes and results to occur rapidly. The acts of teaching are part of the culture of education. These acts change slowly over time, even with focused efforts. A look at the rapidity with which technology was embraced in many schools over the past two decades provides some notion of how change can occur when teachers work together and consider how to shape and share their knowledge of content, curriculum, learners, and assessment.

Teachers as Learners

The development and practice of new methods for teaching has to be balanced with learning new topics in the curriculum. New topics call for development of new knowledge, curricular revisions, and topic-specific teaching approaches. To address this need, actions should include building communities of professional scientists, science educators, and teachers focused on identifying relevant and meaningful content for the curriculum, ways of structuring that content, and activities for teaching and assessing student mastery of major concepts, principles, and procedures. Such communities should open up avenues of communication in all schools, among all concerned, to ensure that the science being taught is meaningful science and that it is being taught in useful ways. Opportunities to work across different levels of schooling also assist in articulating programs and seeing that change, as it relates to a new topic, occurs in manageable ways.

The above comments not withstanding, the most important feature of professional development for the teaching of science is that it extends over the teachers' careers. Given the rapid growth of the sciences and the approaches and technology available for teaching science at middle school and high school levels, teachers need to continually update their professional knowledge. Learning to teach and becoming excellent at it is a life-long process that requires not only the development of very practical and complex skills under the guidance and supervision of experts, but also the acquisition of specific knowledge and the promotion of certain ethical values and attitudes. In addition to 'knowing what", and "knowing how", teachers must learn "knowing why", and "knowing when"[19]. They need time for consideration of new material and ways in which that material might be studied in their classrooms. Professional growth around science and its teaching requires time, constant attention, and sustained opportunities for interaction of all involved[12].

Teachers as Strategists

Professional growth must also consider the reaction of teachers and schools to the expansion of evaluation programs focusing on accountability and high-stakes reporting about schools and students' achievement. The growth, and public prominence, of such evaluation programs has led to deterioration of many curricula, as schools react by teaching to the test in inappropriate ways[20]. Teachers and curricular specialists need assistance in balancing the need for remediation with the need for added opportunities to learn. Teachers need assistance in learning how to respond to accountability systems with a focus on creating opportunities for all students to encounter and learn the appropriate science, be it the development of new content or the analysis of previously learned material.

A major aspect of teacher development and support is the ability of a school to establish and maintain an ongoing professional atmosphere focused on student learning. Such an environment has both the physical surroundings and supporting materials that make high-quality teaching of science possible. As content, teaching, and assessment standards define what the profession and public expect from teachers and students, a like set of standards is needed to define what schools and communities must provide to create the context in which learning can take place[21]. Teachers are energized in direct proportion to the efforts that their schools, administrators, and the public make in supporting their professional growth and maintaining their teaching environment.

To help teachers develop the ability to see the science that they teach from an advanced standpoint and to enable them to translate their understanding into effective instruction, the College Board's programs of professional development focus on workshops built around student-level materials viewed from an advanced standpoint. Such an approach aids teachers to:

- Recognize and learn how to select important topics that exemplify the unifying ideas and the content and processes standards such as those in the AAAS recommendations.
- Apply knowledge of student learning principles in designing and delivering instruction.
- Listen to students to understand their thinking and assess their understanding.
- Set aside time to reflect on classroom practice and make adjustments for the future.

This approach to professional development involves teachers in relating the content outlines mentioned earlier to the development and teaching of central concepts, processes, and procedures as part of the school program. The development of teacher understanding of the relationships and connections existing in the content, both on a theoretical level and in instructional sequencing, better prepares teachers to provide instruction that fosters like understanding in their students.

Part of developing an understanding of content for teachers is helping them deal with individual differences in learners and differential levels of student motivation toward learning science. This includes helping teachers recognize and select optimal patterns for employing different pedagogical approaches at appropriate times, partially based on meeting learner needs and partially based on the relationship of the approaches to learning to the type of content and learning that makes up the heart of a given lesson. Professional development programs, therefore, must aid in developing teachers' abilities to:

- Help students recognize and focus on unifying concepts and procedures connecting these ideas to the real world outside the classroom and to other subjects.
- Help students, via questioning and ongoing self-assessment of their progress, engage in science at a level of understanding beyond surface-level replication.
- Help students, and groups of students, focus on understanding, reflective thinking, and reasoning, rather than only on procedures and superficial analysis in an attempt to find quick answers.
- Support student use of technology and problem-solving strategies in confronting challenging and/or non-routine problems, and in investigating new content and situations.
- Bolster students' vision of themselves as confident and productive science learners.

Teachers as Managers

Professional development of teachers of middle and high school science must also include helping teachers become more efficient managers of their classrooms. Management skills can run the gamut from developing efficient ways of reducing downtime to structuring the environment to eliminate distractions and promote on-task behavior in all students. With the move to block scheduling, longer class periods, and potential gaps in students' enrollment in science classes, teachers will need to develop approaches to deal with content and administrative structures. Professional development may deal with learning to:

- Structure learning environments in which students work collaboratively and with perseverance to complete performance-based and open-ended tasks.

- Establish norms for group work in the classroom that encourage understanding and broad use of representations.
- Develop reasonable time allocations for long-term curricular plans and daily classroom learning activities to achieve both long-term and daily curriculum goals, while fostering high-quality student learning.
- Plan and deliver high-quality instruction within the boundaries of their school's scheduling organization—blocks, semester courses, or year-long courses.

The development of these management capabilities in teachers will require that professional development activities provide teachers with experiences that they, in turn, are expected to provide for their own students. This means extending their understanding of unifying concepts and their fundamental applications as well as their applications in real-world settings.

Teachers as Professionals

Through their professional development activities, teachers should come to see the curriculum from an advanced vantage point, a view that provides them with a solid grasp of the science, and how it is taught, in an interval that begins at least three years prior, to a point at least three years beyond, the levels they teach. In this way, teachers will have a clear view of what and how they teach, one that builds on students' prior experiences and provides a foundation for topics they will encounter in later years.

Part of this viewing of content and instructional approaches from an advanced standpoint should also examine the relative strengths and weaknesses of various representations of fundamental concepts and algorithms. As noted earlier, as students shift between the representations, they need to develop a feel for which representations may be more fruitful in a given setting and which representations may better communicate and provide a basis for reasoning and justification activities.

Professional development materials and activities should call upon teachers to reflect on and provide justifications for their actions, to consider whether their current work is productive and goal-directed, and to determine to what degree their "solutions" really answer the questions asked. By emphasizing strong communication on the part of teachers, these materials provide them with concrete evidence of how students are thinking about science content. Such evidence is a fundamental component of the embedded formative diagnostic assessment about what the individual student knows and how he or she knows it. Once a teacher understands what the individual student knows and how he or she knows it, that teacher is better able to respond with follow-up instruction to take the student to a higher level of understanding.

Technology and Teaching

The College Board provides leadership in defining expectations for students' use of technology. At the same time, the Board aims to help develop teachers' capabilities to use technology in classrooms. The need to utilize technology in the science classroom is essential if students are to be prepared for success in a technological world. However, the use of technology in itself is not the goal but should be implemented to enhance science learning. The potential benefits for students and teachers who utilize technological resources in the science classroom are enormous.

Data acquisition is a key component in the science classroom. When technology is used to collect data, students are afforded more time on tasks to explore and think deeply about the science and propose valid explanations of scientific investigations. The abilities to find, access, manipulate, and interpret data are essential skills for future scientists and for a scientifically literate population.

Vertical alignment of technology use will provide students with necessary tools to be competitive in post-secondary courses. Technology and skills must be introduced at a pace and level that allow students to gain mastery, without allowing mastery of technology to get in the way of learning the scientific concepts.

Utilization of the graphing calculator in the middle grades will enable students to begin a natural connection between the scientific data acquired in the laboratory to the mathematical models that prove our scientific laws. A continuous discussion of mathematical models should be introduced appropriately throughout the science courses. Aligning science curriculum with mathematics will equip students with tools needed for further scientific investigations.

The National Science Education Standards suggest that students develop an appreciation of technology and its influence and impact on science and society. Though sophisticated instrumentation may not be available to the K-12 classrooms, a wide variety of options exist to enhance student learning and appreciation. Possibilities might include the use of probeware, various software packages such as graphing tools and virtual experiments, on-line web activities, and digital libraries.

Multimedia should play a prominent role in the best practice classroom. Scientific concepts are often difficult to grasp. We should strive to engage as many learning styles as possible on any given day. Students need the opportunity to see, hear, or manipulate the subject under discussion. Molecules' interacting becomes visible with a computer program. Electronic homework software or on-line electronic homework benefits students by providing immediate feedback often with a tutorial to help avoid misconceptions that students might encounter if they work a series of problems incorrectly.

A few benefits cited in support of technology use in the classroom include:

- Enhancing interest and motivation.
- Providing access to information.
- Allowing active, manipulable representations.
- Structuring the process with tactical and strategic support.
- Diagnosing and correcting errors in a timely fashion.
- Managing complexity and aiding production.[22,23]

Both teachers and students should use technology as tools in their personal investigations. The use of technology creates a context where knowledge and skill are authentically anchored. Students should develop the capability to translate input and output from technology into written accounts and communicate coherent results of scientific investigations. Students become "thinkers" instead of "sponges" when technology is used appropriately in the classroom. Teachers and students should develop a vision of purposive use of technology as they progress from middle school to the end of high school.

Technology changes at a rapid pace. Schools must strive to ensure that technology in the science classroom closely mirrors available and appropriate technology outside of the classroom. Schools should seek funding to ensure that all students have access regardless of socioeconomic situations.

Summary

The College Board works to create, extend, and improve ways in which teachers can develop into a community of scholars devoted to high-quality teaching and learning of science. The community will share a common set of goals and expectations for students relative to science and the student learning that assists students to master the science desired. This effort involves teachers, schools, communities, the professional societies (such as NSTA, AAPT,

ACS, and ABT), and the College Board, all working together to develop structures that will allow collaboration and emphasize student learning of science from a learning-based instructional viewpoint.
As part of their professional development, teachers must have support and experiences that inform and engage them in developing the new pedagogical skills and content knowledge. Teachers require assistance in dealing with individual differences to incorporate both diversity and equity, to make sure that each student achieves excellence in science and continues to study meaningful science across the entire span of their K–12 education. Teachers require innovative support networks to assist with students who have significant learning problems in science, students who may need extra time and extra assistance in meeting the goals held for all students. This support must be readily available and be provided as quickly as its need is identified.

A forward-looking professional development program will provide teachers with experiences in learning science in active, engaging environments that make them use and experience the same processes and activities that they, in turn, will use with their students. It will allow teachers to reflect on the purposes of such activities, relating them to unifying concepts and the standards and expectations, from both policy and resource allocation viewpoints. To do less leaves teachers unprepared to deal with parents or with financial and administrative structures in which student learning takes place. Part of the professional development process also involves parents, administrators, and the public. These individuals should be aware of the capabilities that students are expected to acquire as part of their science education. The purpose is to inform parents and the public about the ways in which the science program helps to prepare students to be functioning and involved citizens in society.

Conclusion

The present framework details contemporary principles of productive learning, high-quality teaching, professional development of teachers, use of technology, and assessment and evaluation.

We can move the agenda forward by focusing on the improvement of the learning of the sciences, beginning with helping teachers develop and expand their pedagogical practices in the context of improved understanding of the content and its relationship to learning. Improvement of learning also involves increased knowledge of assessment techniques and technology usage as integral parts of the learning environment. As teachers learn to carefully select, adapt, and extend resources, they are better able to help their students prepare for college success.

Furthermore, we can improve learning through the careful development and delivery of professional development programs. These programs should be organized so that teachers see the vertical alignment of the ideas in the curriculum and are prepared to work with students across a span of time, from at least three years below to three years above the level at which they currently teach. These professional development programs ought to be structured around the learning principles cited earlier. Professional development activities must provide teachers with a strong background and personal experience in teaching from a reflective standpoint, listening to their learners, and letting learning guide the way, while, at the same time, focusing on the core materials students are expected to learn. Helping teachers learn to modulate the competing forces of expectations with learning will help move science education forward. It is only through coordinated work involving instruction, assessment, and professional development that science education will change for the better.

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