Research-Based Strategies Used to Develop

- Chemistry: Matter and Change
- Chemistry: Concepts and Applications
- Physics: Principles and Problems
The National Science Education Standards consist of four overarching principles (Figure 1) and a total of 50 specific standards in the areas of Science Teaching, Professional Development for Teachers of Science, Assessment in Science Education, Science Content (broken down by topic area and grade levels), Science Education Program, and Science Education System. To say that the Science Standards have raised the bar for science education in the United States is truly an understatement. Never before has science education been guided by a national set of principles and standards. Never before have our science education goals been set this high. And never before have science teachers and administrators been this challenged to meet goals of excellence in science programs.

Science teachers always have worked to motivate students to read science texts, coordinate visual and verbal information, and study using effective, research-proven strategies. However, teachers have limited resources and must choose how much time and energy to devote to helping students develop these strategies while still allowing them to become self-reliant and independent learners. Administrators and teachers are challenged to reach multiple goals, simultaneously helping students to:

- understand and remember standards-based science and apply it to new contexts,
- perform well on high-stakes achievement tests,
- prepare to succeed in their next science course, and
- become productive and scientifically literate citizens.

The Science Standards describe a vision of the scientifically literate person and present criteria for science education that will allow that vision to become reality. But now, more than ever, science educators are struggling to find appropriate resources to help them meet the ideals set by the Science Standards. This paper focuses on the Science Standards as they apply to high school, as well as the resources now available to those involved in high school chemistry and physics education.

Science Standards’ Four Principles

- Science is for all students.
- Learning science is an active process.
- School science reflects the intellectual and cultural traditions that characterize the practice of contemporary science.
- Improving science education is part of systemic education reform.

For more information, see the National Research Council’s National Science Education Standards (1996) available at www.nap.edu.
CHANGING PEDAGOGY: INQUIRY-BASED SCIENCE LEARNING

To support the Teaching, Professional Development, Assessment, Content, Program, and System Standards, the Science Standards begin with the four guiding principles. One principle stressed consistently throughout the standards is that learning science should be an active process.

**Teaching Standard A:**
Teachers of science plan an inquiry-based science program for their students.

**Content Standards—(Grades 9–12)**
**Science as Inquiry/Content Standard A:**
As a result of activities in grades 9–12, all students should develop

- Abilities necessary to do scientific inquiry.
- Understandings about scientific inquiry.

**Science Education Program Standard B:**
The program of study in science for all students should be developmentally appropriate, interesting, and relevant to students’ lives; emphasize student understanding through inquiry; and be connected with other school subjects.

This stress on inquiry learning, through laboratory activities and other methods, has been echoed in the position statements of the National Science Teachers Association, the American Association of Physics Teachers, and the American Chemical Society Committee on Education, shown in Figure 2, all of which strongly support the Science Standards. The repeated recommendations to use an inquiry approach reflect the growing trend toward constructivism in science education. Constructivism is based on the concept that students construct their own knowledge in a process that is both individual and social. Research shows that teachers cannot simply transfer knowledge to students by lecturing or assigning readings. Students have to take an active role in their own learning. To accomplish this, science

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**Figure 2**

**Statements on Inquiry Learning and Laboratory Activities**

**NSTA Position Statement – The National Science Education Standards:**
The National Science Teachers Association strongly supports the National Science Education Standards by asserting that:

- Teachers, regardless of grade level, should promote inquiry-based instruction and provide classroom environments and experiences that facilitate students’ learning of science...
- Inquiry should be viewed as an instructional outcome (knowing and doing) for students to achieve in addition to its use as a pedagogical approach...
- Science programs should provide equitable opportunities for all students and should be developmentally appropriate, interesting and relevant to students, inquiry-oriented, and coordinated with other subject matters and curricula.

(Adopted by the NSTA Board of Directors, January 1998. For more information, see [www.nsta.org](http://www.nsta.org).)

**American Chemical Society Committee on Education – Science Education Policies for Sustainable Reform (2001):**

Science curricula need to be challenging to the students, and based on the “real world” of student interactions with nature...Inquiry-based learning and laboratory experiences are essential components of chemistry instruction.

(For more information, see [www.chemistry.org](http://www.chemistry.org).)

**AAPT Committee on Physics in High Schools Position Paper – The Role of Laboratory Activities in High School Physics:**

Theory and research suggest that meaningful learning is possible in laboratory activities if all students are provided with opportunities to manipulate equipment and materials while working cooperatively with peers in an environment in which they are free to pursue solutions to problems that interest them...The role of the laboratory is central in high school physics courses since students must construct their own understanding of physics ideas. This knowledge cannot simply be transmitted by the teacher, but must be developed by students in interactions with nature and the teacher. Meaningful learning will occur where laboratory activities are a well-integrated part of a learning sequence.

(Approved by the AAPT Executive Board, November 1992. For more information, see [www.aapt.org](http://www.aapt.org).)
programs must include ample opportunities for students to explore, experiment, question, debate, discuss, and discover.

This is not to say that teachers are removed from the educational process. Rather, the learning experience should include an appropriate balance of explicit and implicit instruction. Implicit instruction occurs when students figure out for themselves how to grapple with problems and construct conceptual knowledge (Pressley et al., 1992; Shulman & Keisler, 1966). This is encouraged when students engage in project-based and subject-integrated science activities, open-ended science labs, and science fair projects. Explicit instruction occurs when teachers and textbook authors clearly explain science concepts and problem-solving strategies to students in a direct, low-inference fashion (Duffy, 2002).

Explicit instruction also provides students with needed background knowledge on how, why, and when to use learning and studying strategies. This leads to learner independence (Zimmerman, 1998, 2000, 2001) and productive dispositions toward achievement (Alderman, 1999). Explicit instruction is critical to good science teaching. Exclusively using implicit instruction often fails to equip developing students with the necessary reading, writing, and studying strategies (Graham & Harris, 1994, 2000).

Teachers, curricula directors, and administrators are left with a difficult task: How can we design a science program that provides the right balance of implicit and explicit instruction and includes a curriculum with the proper age-appropriate content and ample opportunities for exploration and inquiry learning?

SUPPORTING THE SCIENCE STANDARDS

One of the concepts explained in the Science Standards is that the Standards are meant to serve as descriptive ideals and guidelines. They represent what can be accomplished, but leave the specifics of implementation to others. The responsibility for putting the vision of the Science Standards into action belongs to everyone with an interest in science education: teachers, students, administrators, supervisors, policymakers, assessment specialists, scientists, teacher educators, parents, businesses, local community members, curricula developers and publishers. Glencoe/McGraw-Hill, one of the nation’s largest textbook developers, has risen to the challenge of the Science Standards and created inquiry-based programs for high school chemistry and physics. Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems respond to the need of science educators for curricula that accomplish multiple goals. To help educators reach the Science Standards goals, such curricula must:

■ Support the recommended Content Standards,
■ Give students consistent opportunities for active and extended science inquiry,
The Inquiry Teaching Approach

Teaching science using an inquiry approach means teachers must go far beyond merely lecturing students and encouraging them to memorize fact-based lecture notes and textbook explanations in preparation for exams. Rather, students should be allowed to experience the scientific process as scientists do, developing critical-thinking and problem-solving skills through the use of engaging activities and active learning strategies. Both the National Science Education Standards’ Teaching Standards and Content Standards put high value on inquiry as an important component of science teaching and learning.

According to the National Research Council’s Committee on Developing the Capacity for Selecting Effective Instructional Materials,

The Standards encourage teachers to engage students in the process of scientific inquiry by directing them to ask questions about the natural world, design experiments to answer these questions, interpret the experimental results, and discuss the results with their peers. Such inquiry-based teaching enhances student understanding of scientific concepts and it is intended to equip all students with the analytical skills they will need in the future to interpret the world around them (p. 6).

(For more information, see Selecting Instructional Materials: A Guide for K–12 Science, available at www.nap.edu.)


Foster Continuing Inquiry. Through questioning, self-assessment, and redesign of traditional hands-on experiences to open-ended ones, constructivist teachers must constantly arrange learning environments that challenge students to create more accurate knowledge for themselves. Constructivist research may be disconcerting to traditional lecture-oriented education programs, but it presents strong empirical data for what we regard as ‘best practice’ in science education.


- Provide opportunities for scientific discussion and debate,
- Provide various tools to regularly assess student understanding, and
- Connect science to other areas of learning, including natural phenomena and science-related social issues that students discover in everyday life.

The approach of all three programs allows students to discover concepts within each of the Content Standards, giving them opportunities to make connections between chemistry and physics concepts and the real world. All three programs’ Teacher Wraparound Editions include Chapter Organizers at the beginning of each chapter, which clearly outline the Science Standards covered in each section.

REACHING THE SCIENCE STANDARDS—RESEARCH-BASED STRATEGIES

To fulfill the characteristics of standards-supporting curricula, Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems were developed using six specific, research-based instructional strategies. These strategies support inquiry-based instruction by providing ideas for and examples of how scientific inquiry can be conducted and by providing information to support student inquiry. The six strategies are as follows:

1. Using prior knowledge to learn new information and correct misconceptions

When students recall previously learned information, they can learn new, related information more effectively. Strategies to do this include: 1) recalling information, asking questions, and using analogies; and 2) elaborating on information from the textbook or teacher. In-text questions that ask students to use prior knowledge may remind them of information already in their long-term memory that, for some reason, is not easily remembered (Bransford, 1979; Pressley & McCormick, 1995). This research-based strategy also is central to successful reading and writing performances (Guthrie & Alvermann, 1999; Holliday et al., 1994).
Another advantage of using prior knowledge and linked topics to learn new information is that it provides an opportunity to correct misconceptions. Effective teaching elicits students’ prior conceptions and provides opportunities to extend or challenge those understandings (Donovan et al., 1999). With Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems, students learn to recognize their prior conceptions and evaluate them using scientific evidence. Each program’s Teacher Wraparound Edition includes sections on misconceptions that suggest strategies for eliciting and correcting students’ misconceptions about specific ideas covered in each chapter, as seen in Figure 3.

2. Practicing important tasks

Providing students with opportunities to practice important tasks has long been considered a successful strategy to improve understanding and memory. Giving students individual feedback on their practice helps in monitoring and fostering science learning (Baker, 1991). Practicing helps students acquire additional information as they search and productively struggle, with teacher help, for the understanding and application of science information. Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems were designed with the philosophy that practice is absolutely necessary for learning to occur.

Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems have a variety of features to allow for extensive practice in scientific skill development and test preparation. These features include: example problems (as shown in Figure 4A), practice problems, problem-solving strategies, challenge problems, embedded reading and writing exercises, and multiple laboratory activities (including Launch Labs, Problem-Solving Labs, Mini Labs, ChemLabs, Try at Home Labs, Discovery Labs, Physics Labs, Design Your Own Physics Labs, and Internet Physics Labs). These opportunities for practice allow students to fine-tune their problem-solving abilities and learn new information, which will be indispensable for solving problems on standardized tests. All three texts also offer Standardized Test Practice sections that review and reinforce content in a standardized format.

3. Using high-quality visuals to communicate, organize, and reinforce science learning

Visuals—such as complex diagrams and elaborate line drawings—used in conjunction with verbal descriptions increase students’ chances of learning, understanding, and remembering relationships and subtle properties of science concepts and problems. Visuals often are the only way to effectively communicate the central concepts needed to understand chemistry and physics. Students are able to organize and group ideas when visuals illustrate different and common characteristics (Hegarty et al., 1991). Also, the mental images that high-quality visuals stimulate are an indispensable tool for recalling information, especially compared to information presented with only text or lower-quality visuals (Willows & Houghton, 1987).
Each text also is accompanied by an array of supplementary materials that allow for the use of visuals, including: Interactive Chalkboard CD-ROMs, Virtual Labs CD-ROMs, WebQuest online research projects, Internet Labs, and other online resources at chemistryca.com, chemistrymc.com, and physicspp.com.

4. Motivating all students to achieve

Students are motivated to learn when materials provide explicit, attractive, relevant-to-student presentations of key concepts (Alderman, 1999; Corno, 1994). Motivational strategies also can include long-term projects of real-world relevance, and carefully constructed problem-solving activities that require effort, persistence, and flexibility. Effective strategies also include using examples from many cultures, using a variety of teaching techniques, and incorporating cooperative learning activities (Banks, 2001; Winzer & Mazurek, 1998). Research has shown that the inquiry learning and cooperative learning approaches work well for all students, including English-Language Learners and those with learning disabilities (Rosebery et al., 1992; Stoddart, 2002; Scruggs et al., 1993). Such motivational strategies will stimulate scientific curiosity and instill confidence through scientific exploration and discovery. Group activities also promote positive attitudes toward learning by building a community of learners (Brown & Campione, 1994).

Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems provide students with exciting opportunities to explore chemistry and physics from many different perspectives, shown in Figure 4C. Many features—How It Works, Why It’s Important, Technology and Society, Future Technology, Problem-Solving Labs, Discovery Labs, Consumer Chemistry, Applying Chemistry, and Applying Physics—encourage student curiosity and link chemistry and physics topics to everyday life. In all three programs, group activities, discussions, and multiple labs help students become part of an engaged community of learners.

All three programs also include multiple strategies in the Teacher Wraparound Editions for reaching all students, including English-language learners, struggling students, and gifted students. Elements include: Differentiated Instruction, Visual Learning, Cultural Diversity, Challenge Activities, and Helping Struggling Students. Forensics Laboratory Manuals allow all students to explore chemistry and physics topics in fun and engaging ways.

Figure 4

A Example Problems provide students with opportunities to practice important tasks.
B High-quality illustrations and photos help communicate concepts.
C Relevant activities and topics, such as Chemistry and Technology features, motivate students to achieve.
5. Developing reading comprehension strategies and mathematical skills

Success with scientific skills is strongly tied to competency in reading and mathematics. Important reading and decoding strategies include: 1) pronunciation and word origin guides to facilitate decoding of unfamiliar words; 2) questions and practice items for self-assessment of reading comprehension and conceptual understanding; and 3) reading exercises designed for students to solve verbally presented problems and comprehend complex prose. Students need to read from textbooks that are challenging and that contain science vocabulary compatible with their prior knowledge and academic abilities (Guthrie & Alvermann, 1999; Holliday et al., 1999). Students also need pronunciation and other language-learning information to decode words, a prerequisite to reading comprehension (Pressley & Block, 2002). Students must have opportunities to engage in writing (Graham & Harris, 2000) and establish reading comprehension strategies such as questioning, visualizing, clarifying, elaborating, inferring, concluding, summarizing, and predicting (Pressley, 2002). These reading, decoding, and writing skills help students to remember important ideas needed to learn new information, understand information required to practice important tasks, and develop verbal skills needed to perform well on achievement tests and later in life. Another area strongly related to science learning is mathematics. Mathematical concepts, such as ratio, rates, proportion, percent, measurement, graphing, data analysis, statistics, and probability are crucial in the development of scientific reasoning (Lehrer, 2003).

Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems were designed with thorough and consistent integration of reading and mathematics skills. All three programs incorporate reading and writing development sections, such as: Vocabulary, Word Origin, Portfolio, Reading Chemistry, Writing in Chemistry, Writing in Physics, Chemistry Journal, and Glossaries (refer to Figure 5). Supplementary materials, such as Vocabulary PuzzleMaker software and the Reading and Writing in the Science Classroom handbook offer further ideas for incorporating reading and writing activities. Mathematical concepts also are incorporated into each chapter of the three programs, through such features as: Critical Thinking, Reinforcement, Practice Problems, Connecting Math to Physics, Problem Solving Strategies, and references to Computations with the Calculator and Math Handbook Appendices.

6. Learning by using study strategies

According to the research literature, there are no shortcuts to learning, but study strategies help students understand, organize, remember, and apply new information presented in science textbooks (Bransford, 1979; Corno, 1994). Study strategies used to learn from textbooks include concept mapping, highlighting, outlining, note taking, summarizing, and underlining (Peverly et al., 2003). These study skills promote learner activity, improve metacognition, and provide an effective form of review for tests (Hattie et al., 1996; Carter & Van Matre, 1975).


VERIFYING LEARNING—ASSESSMENTS OF STUDENT UNDERSTANDING

Another key concept stressed in the Science Standards is the importance of continuously assessing student understanding.
Teaching Standard C:
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.

Assessment provides opportunities for feedback, and research has shown that the most improvement occurs when feedback is given often and immediately following tests or activities (Bangert-Drowns et al., 1991). Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems offer teachers many choices to probe students’ understanding of key concepts and skills. Assessment features include: Section Assessments, Chapter Assessments, Standardized Test Practice, Portfolios, and Daily Intervention. Supplemental materials such as Performance Assessment in the Science Classroom and the ExamView® Pro Testmaker CD-ROM provide additional support for ongoing assessment.

REACHING EVERY LEARNER—SCIENCE FOR ALL STUDENTS

Another key principle of the National Science Education Standards is that science is for all students. Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems offer a variety of instructional methods for all ability levels—reading, writing, graphics, hands-on labs, and much more.

Differentiated Instruction elements in each Teacher Wraparound Edition provide ideas to engage all students, including gifted students, English-language learners, and students with special needs.

Intervention and Remediation: Check for Understanding features in each Teacher Wraparound Edition and supplements such as Supplemental Problems and Mastering Concepts in Chemistry each offer additional assistance for struggling learners.

ELL Strategies for Science offers specific strategies for integrating science and language learning.

Enrichment and Challenge: Each program creates opportunities for gifted students to enrich their learning. Supplements such as Pre-AP/Critical Thinking Problems, Additional Challenge Problems, Enrichment worksheets, and Forensics Laboratory Manuals offer a variety of ways to extend challenges to gifted students.

Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems each are complemented by a full line of multimedia resources that offer a range of technology options to enhance skills, promote critical thinking, and connect the classroom to the world in which students live. Multimedia resources include MindJogger Videoquizzes, Interactive Chalkboard CD-ROM, ExamView® Pro Testmaker, StudentWorks™ CD-ROM, and TeacherWorks™ CD-ROM. By offering such diverse resources and learning tools, these programs ensure that every student can reach the goals set by the National Science Education Standards.

SUMMARY

The National Science Education Standards have provided a new gold standard in science education. More than ever before, high school science teachers and administrators are being called upon to challenge their students in becoming inquisitive and active science learners. To achieve the high goals set by the Science Standards, educators and others involved in science education reform will need to use an array of state-of-the-art strategies and tools. Their toolbox must include inquiry-based curricula that support the Science Standards in every way. Glencoe/McGraw-Hill is proud to offer Chemistry: Concepts and Applications, Chemistry: Matter and Change, and Physics: Principles and Problems. With their focus on inquiry learning and continuous assessment, teachers can achieve the goals set by the National Science Education Standards, now and in the coming years.

<table>
<thead>
<tr>
<th>Learning Strategy</th>
<th>Select Examples from <em>Chemistry: Concepts and Applications (CCA)</em>, <em>Chemistry: Matter and Change (CMC)</em>, and <em>Physics: Principles and Problems (PPP)</em></th>
</tr>
</thead>
</table>
| Using prior knowledge to learn new information and correct misconceptions | **CCA–Student Edition (SE):** 71, 153, 190, 692; **Teacher Wraparound Edition (TWE):** 18, 38, 303, 486, 711  
**CMC–SE:** 92, 234, 489; **TWE:** 56, 352, 538  
**PPP–SE:** 119, 327, 342, 431; **TWE:** 155, 263, 489, 643  
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**Section Focus Transparencies** |
| Practicing important tasks | **CCA–SE:** 122, 328–329, 408; **TWE:** 313, 617  
**CMC–SE:** 29, 519, 707, 775; **TWE:** 60, 104, 268, 672  
**PPP–SE:** 332–333, 418, 572, 721; **TWE:** 214, 345, 543, 564  
**Interactive Chalkboard CD-ROM** and **Video Labs** |
| Using high-quality visuals to communicate, organize, and reinforce science learning | **CCA–SE:** 152, 464, 602; **TWE:** 574, 711  
**CMC–SE:** 418, 522, 534; **TWE:** 264, 292, 453  
**PPP–SE:** 226, 484, 582, 724; **TWE:** 315, 407, 567  
**Virtual Labs CD-ROM, Video Labs, Interactive Chalkboard CD-ROM, StudentWorks™ CD-ROM**  
**Teaching Transparencies** |
| Motivating all students to achieve | **CCA–SE:** 128, 659, 868; **TWE:** 391, 469, 556  
**CMC–SE:** 210, 302, 660, 959; **TWE:** 188, 338, 402, 651  
**PPP–SE:** 110, 160, 173, 450; **TWE:** 288, 353, 356, 388, 505  
**Forensics Lab Manual** |
| Developing reading comprehension strategies and mathematical skills | **CCA–SE:** 403, 544, 690, 707; **TWE:** 398, 555, 631  
**CMC–SE:** 52, 121, 204, 887; **TWE:** 121, 260, 284  
**PPP–SE:** 272, 441, 460, 630, 742, 745; **TWE:** 106, 151, 244, 260  
**Vocabulary PuzzleMaker**  
**Reading and Writing in the Science Classroom, English-Language Learner’s Strategies for Science** |
| Learning by using study strategies | **CCA–SE:** 202, 224, 508, 521; **TWE:** 370, 395  
**CMC–SE:** 205, 351, 526; **TWE:** 21, 389  
**PPP–SE:** 221, 380, 478; **TWE:** 391, 624 |
| Verifying learning with assessment | **CCA–SE:** 508, 521; **TWE:** 305, 509, 779  
**CMC–SE:** 65, 205, 306–311, 351, 526; **TWE:** 85, 97, 128, 203  
**PPP–SE:** 499, 545; **TWE:** 75, 145, 358, 823  
**Performance Assessment in the Science Classroom**  
**Online quizzes at chemistryca.com, chemistrymc.com, physicspp.com**  
**ExamView® Pro Testmaker, Vocabulary PuzzleMaker** |
REFERENCES


