AP Chemistry: Course and Exam Review

by Jim Spencer and John Hnatow

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Introduction

In 2002, the National Research Council Center for Education, Division of Behavioral and Social Sciences and Education published a report: *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools* (National Research Council, 2002). The two-year study was based on current research upon learning and program design. The Advanced Placement, AP, and International Baccalaureate, IB, programs were evaluated, and recommendations were made on how these and other advanced study programs could become more effective and more accessible to students.

Among the principal findings of the NRC Chemistry Panel:

- The AP and IB final examinations are formulaic and predictable in their approaches and question types from year to year.
- Thus, with sufficient practice on how to take such examinations and enough drill on major concepts that the examinations are likely to test; students can score well on them primarily by rote, without actually understanding the major concepts associated with the topics being tested.
- The AP and IB Chemistry courses to date do not yet recognize the increasingly interdisciplinary nature of modern chemistry; its incorporation of important related fields,

such as materials science and biochemistry; and the opportunities presented by such fields to teach related chemical concepts in a contextual manner.
- The AP and IB examinations do not reflect recent developments in chemistry and in the teaching of chemistry at the college/university level.

Subsequently, the NRC Chemistry Panel made these specific recommendations:

Any high school course in chemistry that is labeled as advanced study, whether it is structured according to an established curriculum and assessment (such as AP or IB) or otherwise, should enable students to explore in greater depth the chemistry concepts and laboratory practices introduced in the first-year course and, where appropriate, to conduct some form of research or independent inquiry. Under the guidance of a qualified advanced study instructor, desirable features of such advanced study would include some combination of these characteristics:

- application of basic ideas to complex materials, systems, and phenomena
- use of modern instrumentation, methods, and informational resources
- integration of concepts within and between subject areas, including extensions to other disciplines
- use of appropriate mathematical and technological methods
- extended use of inquiry-based experimentation
- development of critical thinking skills and conceptual understanding
- use of appropriate assessment tools of student performance that reflect current best practices
- promotion of communication skills and teamwork.

To be effective, advanced courses in chemistry must reflect recommendations in the areas of content, pedagogy, and assessment as described in the *National Science Education Standards* (NSES) (National Research Council, 1996).

Overarching Goals

The College Board immediately reacted to these findings and recommendations by undertaking a study of how to promote learning with understanding. Representatives of the College Board began consultation with the National Science Foundation (NSF) on possible changes that could be made to improve the learning environment in the sciences. Although AP courses and exams are successful imitations of typical introductory courses at colleges, the College Board has decided that it is insufficient for AP courses simply to reflect existing college courses if those courses do not represent instructional practices which promote deep learning and conceptual understanding. The College Board was urged to take AP one step further to emulate only those college courses that reflect the NSES standards. Up-to-date information is available on the College Board's AP Central Web site at http://apcentral.collegeboard.com/apc/Controller.jpf (last accessed March 21, 2008).

The AP program is subject to certain existing constraints:

- As a credit-by-examination program, AP must prepare students to succeed in sequent courses in each subject area.
- AP exam scores must be comparable to introductory course grades for predicting student performance in sequent courses.
- Any proposed redesign must maintain AP's ability to meet these requirements.

Within these existing constraints, the College Board has committed to the following guiding principles for the development of a revised AP Chemistry Course and Exam:

- Learners have different strategies, approaches, patterns of abilities, and learning styles that are a function of the interaction between their heredity and their prior experiences.
- Learners' motivation to learn and sense of self affect what is learned, how much is learned, and how much effort will be put into the learning process.
- The practices and activities in which people engage while learning shape what is learned.
- Learning is enhanced through socially supported interactions.
- Learning with understanding is facilitated when new and existing knowledge is structured around the major concepts and principles of the discipline.
- Learners use what they already know to construct new understandings.
- Learning is facilitated through the use of metacognitive strategies that identify, monitor, and regulate cognitive processes.

The National Science Foundation and the College Board undertook an ambitious effort with the sole purpose of aligning the AP Chemistry curriculum and the AP Chemistry Exam with introductory college courses that research has identified as those that best facilitate deep learning. The partnership between NSF and the College Board in the course and exam review of Advanced Placement science courses is based upon elements known as *overarching goals.* The overarching goals for a new paradigm in AP program development are to

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- increase depth of understanding of essential concepts while also developing capacity to use critical skills within the discipline by limiting breadth of content covered and drawing upon current research and theory on learning, instruction, and assessment to guide the design and implementation process
- infuse the AP science program courses with scientific topics drawn from cutting-edge research and emerging issues
- create science-learning programs accessible to students from a broad range of backgrounds, and
- prepare students for success in subsequent college-level courses within the STEM disciplines and stimulate them to consider careers in science, technology, engineering, and mathematics.

By meeting these goals, the objective of developing the habits of mind that support lifelong learning is addressed. Therefore, with NSF and the College Board's encouragement, an AP Chemistry Course and Exam Review Commission was formed. The Commission consisted of a diverse group of university researchers, chemical educators, and high school teachers. Some of the Commission members are experienced AP Chemistry Readers, Table Leaders, and AP Development Committee members. A listing of Commission members can be found at the end of this report.

The Commission convened four times during 2006–2007, worked between meetings, and applied the National Research Council's recommendations to the production of a new AP Chemistry curriculum, new exam specifications, and directed professional development opportunities. During the first half of 2008, several review panels were convened to review and refine the work of the Commission. These review panels consisted of university faculty, AP Chemistry high school teachers, and learning scientists. These reviews resulted in some of

the following changes: terminology, reorganization, and the condensing and/or expanding of content topics and concepts.

How Students Learn

Changes to the AP Chemistry program will reflect the latest research on how students learn. The course and exam review will emphasize depth of understanding so that students will be better equipped to navigate complex content and to transfer their knowledge during assessments. A "less is more" principle, or the notion that it is better to uncover material than to cover it, will guide the selection of content. The major issues being addressed are breadth vs. depth and how to facilitate the development of advanced learners who choose to pursue additional study in chemistry. At present, there are more topics in the AP and introductory college courses than students can be expected to learn, and no topic receives adequate attention and depth. The solution involves altering the course material and process goals by cutting exercise solving and simple solving of numerical problems from the course. Students both in the lab and lecture should be required to interpret and analyze data (Lloyd and Spencer, 1994). On the basis of the original work of the Commission and the recommendations of the Review Panels, curriculum and assessment models were created which effectively emphasize problem solving, synthesis, and evaluation. The AP course will, to a higher degree, promote conceptual understanding and make connections within the discipline. Accordingly, the newly formed AP Chemistry Curriculum Development and Assessment Committee (CDAC) supervises any subsequent additions and/or revisions to these models.

The long-term goal is to increase scientific literacy and to encourage more students, especially those from groups traditionally underrepresented in the sciences, to pursue advanced-level study in high school and college and, eventually, to pursue science-related careers. All change is intended to help students move seamlessly from high school to college.

The new curriculum model will advocate college courses that research identifies as those with deep learning and conceptual understanding. The AP program has a concern that the amount of content on AP exams is putting inappropriate pressure on teachers to sacrifice depth of study to breadth of coverage. The AP program also has a concern that inquiry-based science learning is not being fostered. The inquiry approach to lessons is less authoritative and formal, more learner friendly, and closer to how scientists operate in the "real" world (American Chemical Society, 2003).

The College Board supports an AP Course and Exam Review that includes curriculum, instruction, and assessment. According to the NRC Report (National Research Council, 2002), a curriculum for high school advanced study

- structures concepts, factual information, and procedures that constitute the knowledge base of the discipline around organizing principles (unifying themes) of the subject area.
- links new knowledge to what is already known by presenting concepts in a logically sequenced order that builds on prior learning;
- focuses on depth of understanding rather than breadth of content coverage by providing students multiple opportunities to practice and demonstrate what they learn in a variety of contexts;
- includes structured learning activities that allow students to experience problem solving and inquiry in situations that are drawn from personal experience and real-world applications;
- develops students' abilities to make meaningful applications and generalizations to new problems and contexts; and
- incorporates language, procedures, and models of inquiry and truth verification that are consistent with the accepted practices of experts in the domain.

Accordingly, science courses

- should maintain students' focus on the central organizing themes, the underlying concepts of the discipline, and the unifying themes that engender further understanding;
- are based on careful consideration of what students already know;
- should focus on detecting, making visible, and addressing students' often fragile, underdeveloped understandings and misconceptions;
- should engage students in worthwhile tasks that provide access to powerful ideas and practices;
- should structure learning environments so students can work collaboratively to gain experience using ways of thinking and speaking used by experts in the subject area; and
- should orchestrate classroom discourse so students can make conjectures, present solutions, and argue about the validity of claims.

In addition, effective assessments are

- based on a model of cognition and learning that is derived from the best available understanding of how students represent knowledge and develop competence in a domain;
- designed in accordance with accepted practices to ensure reliability, validity, and fairness;
- aligned with the curriculum and instruction that the assessment is intended to measure;
- designed to include important content and process dimensions of performance in a subject area and to elicit the full range of cognition;
- multifaceted and continuous when used to assist learning by providing multiple opportunities for students to practice their skills and receive feedback about their performance; and
- designed to assess understanding that is both qualitative and quantitative in nature.

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College Curriculum Study

In 2006, a content expert panel designed an instrument that identified instructional strategies that facilitate deep learning and conceptual understanding in existing college chemistry courses. The panel's selection of these strategies involved an invitation to 851 colleges and universities and a final review of faculty at 400 of these institutions. Experts were asked to nominate faculty who have been recognized for exemplary work teaching the general chemistry courses.

Instructors rated their own courses against the criteria of the instrument. The instrument was administered at colleges and universities where syllabi, assignments at all grade ranges, and exam items were collected.

Then criteria-based ratings were compiled, and nominees from prominent organizations and stakeholders analyzed the collected data and materials. These organizations and stakeholders included NSF, Science Education for New Civic Engagements and Responsibilities, Association for the Advancement of Science, National Association of Biology Teachers, American Institute of Biological Sciences, American Chemical Society, National Association of Environmental Education, AAAP, the AP Development Committee, and the College Board's Science Academic Advisory Committee.

As a result, the College Curriculum Study defined instructional quality in terms of three areas: (*1*) content taught, (*2*) habits of mind produced, and (*3*) teaching strategies and methods. A review panel identified twenty courses as excellent examples of having this type of instructional quality. Fifteen of the twenty courses were then advanced as exemplary college courses based on additional criteria, which included inquiry type learning, active

involvement of students, integration of technology, etc. Courses and materials were compared to the instrument to ensure that they facilitated and promoted deep learning and understanding. Following this procedure and on the basis of a report submitted by the Center for Educational Policy Research (Conley, 2006), four courses were identified as exemplary. The College Curriculum Study also produced *performance expectations* (PEs), statements that reflected both conceptual understanding and reasoning and inquiry within each discipline.

The AP Course and Exam Review Commission members analyzed the discipline domain to gather, organize, and prioritize information that had implications for assessment. This was done in order to arrive at a better understanding of how the unifying concepts were expressed within the discipline and to find and describe the best ways to incorporate reasoning and inquiry. Completion of these tasks has informed the production of the following classroom supports: *AP Chemistry Course Guide*, embedded classroom assessments, new exam specifications, and professional development opportunities.

The Commission focused on what would be considered as evidence of student mastery of concepts. How will the instructor know what constitutes mastery and understanding? For this evidence, the college curriculum study documents can provide examples. This evidence-based part of the redesign of AP chemistry helped to establish course content (Mislevy and Riconscente, 2005). The Commission recommended what information is critical for inclusion in an AP course. Curriculum and assessment, as well as professional development working groups, will work cooperatively to decide how to measure what is taught in an AP context with its particular constraints, as well as how to support AP teacher instructional practices.

Unifying Themes

A domain (subject area) analysis model was developed as a conceptual tool that organized the knowledge, skills, and abilities that should be covered in the AP course. (Incidentally, this was the same organizing structure used across the sciences to highlight similar skills and common content among seemingly unrelated disciplines.) The advantage of the model is that it emphasized connections and helped the commission to move away from viewing the course as a long list of topics.

A preliminary model was shown to the principal investigators from the College Board, who suggested changes, and a draft model was discussed at a meeting of science co-chairs who made changes and approved the approach. The domain analysis model provides a course goal of developing integrated knowledge. It includes disciplinary knowledge organized around unifying themes, the ability to apply concepts, the understanding of connections between facts and concepts, the integration of concepts across the sciences, the ability to use inquiry to gain new knowledge, and the ability to reason scientifically.

With the goal of developing a new curriculum, a domain analysis ensued. This consisted of a detailed description of the structure of knowledge in the discipline. In order to accomplish this, the Backward Design process for curricular design was adopted (Wiggins and McTighe, 1998). Backward Design provides a method of systematically uncovering content by asking essential questions that focus on the big picture, goals for student learning, and pedagogical practice. This methodology begins with an identification of desired results followed by evidence that shows mastery of the concept. First, the linchpin ideas, that is, principles that transcend the discipline, were identified. The College Board recognized the ideas essential to understanding as unifying themes which served as hubs for the Backward Design. A unifying theme is one of a small number (five or six) of the most important organizing principles of the content within the discipline. Identified as "Level one," the unifying themes are conceptual anchors that promote coherence of knowledge and transference. A unifying theme is not to be considered as another fact or an abstract idea; it is to be a pedagogical tool that unifies knowledge and sharpens understanding. The goal is to reduce breadth and increase depth of understanding of the unifying themes. Several considerations related to

them were discussed: (1) the overarching ideas that must be present if this course were the student's only opportunity for college-level study in chemistry, (2) the unifying ideas that must be present if a student will major in chemistry, (3) how such a foundation will serve the needs of subsequent courses, and (4) how students would demonstrate an appropriate depth of understanding of these unifying themes.

A sublevel, "Level two," contains a secondary concept, smaller in scope and related to the unifying theme, which will persist beyond the AP course. Level two consists of enduring concepts, what the student should take away from the course. These Level two concepts are essential knowledge that results from prioritizing and identifying those skills and concepts that have connective and transfer power. These are concepts that must be mastered, so students can perform complex tasks that demonstrate full understanding of the unifying themes at Level one. In the original work of the Commission, 30–40 Level two concepts were identified. The Level two concepts were too broad for course developers and test designers to identify what is and what is not in the course.

Therefore, a third level was required. In 2008, the Level two concepts were reviewed and refined by the Review Panels.

Level three consisted of concepts even smaller in scope and follows from Level two concepts. This level was designed to provide classroom and laboratory experiences that gave depth and understanding to the enduring concepts.

Level three was based on the essential knowledge required to support understanding of Level two. In order for a concept to be included at Level three, it must be integrated with the unifying concepts and scientific inquiry and reasoning.

The Commission and several review panels have identified, reviewed, and refined six unifying themes in the subject area. The unifying themes serve to guide the course and exam review. A draft of these unifying themes is listed in Fig. 1.

Figure 1. *Draft* of Unifying Themes to Guide the AP Chemistry Course and Exam Review

Unifying Theme 1:	The chemical elements are fundamental building materials of matter, and all matter can be understood in terms of arrangements of atoms that always retain their identity.
Unifying Theme 2:	Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.
Unifying Theme 3:	Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Unifying Theme 4:	Rates of chemical reactions are determined by details of the molecular collisions.
Unifying Theme 5:	The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Unifying Theme 6:	Any bond or intermolecular attraction that can be formed can be broken. These two processes are in a dynamic competition, sensitive to initial conditions and external perturbations.

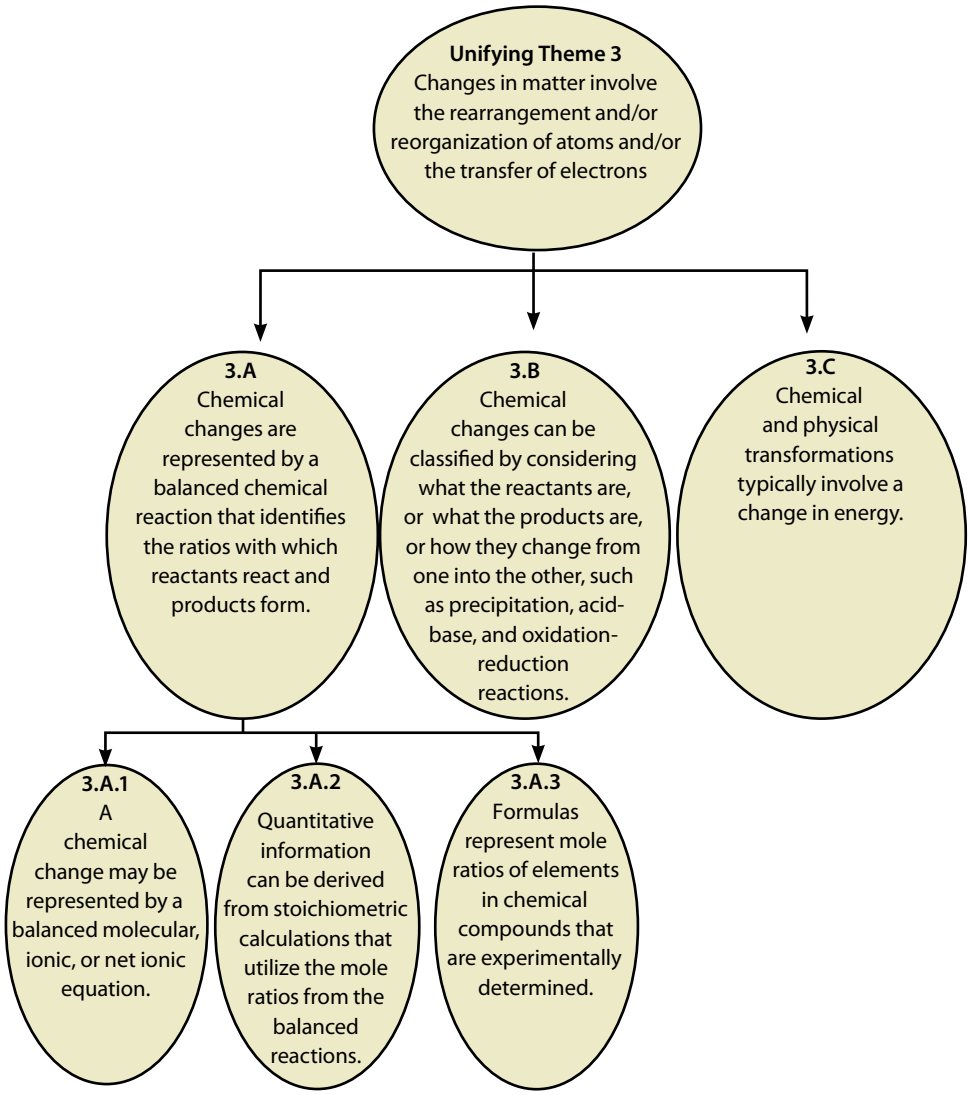
A graphic organizer tool called Inspiration provided commission members a visual representation for the mapping of the domain, and a common language to use among domains. Inspiration assisted the process of the domain analysis by emphasizing the connections of disciplinary knowledge to unifying concepts and inquiry throughout the process. A draft illustration of the use of Inspiration to map Unifying Theme 3 can be found in Fig. 2. This map shows how the unifying themes link to the enduring concepts, Level two, and how the enduring concepts may be strengthened and deepened by Level three.

A Level two concept labeled 3.A in Fig. 2 states that "Chemical changes are represented by a balanced chemical reaction that identifies the ratios with which reactants react and products form." The Commission decided by consensus to remove the rote memorization of solubility rules for reaction prediction exercises and documented this decision process using a tool called the "Reporter." (The *Reporter* is a tool that was developed by the College Board to be used as a product of the domain analysis).

The Reporter addressed and documented the reasoning needed to answer the questions found in the Commission's charge. This documentation was provided to subsequent review panels and the Curriculum Development and Assessment Committee, so that the reports could be used to develop the exam and professional development components of the course. This documentation also included decisions made with a consensus process

to omit certain areas of content from the course. In Level three concept 3.A.3, another documented decision in the Reporter referred to the determination of empirical and molecular formulae. The Reporter recommendation served to exclude the traditional combustion analysis problems, which are rarely done today, but to include specific laboratory activities designed to allow students to determine simple formulas from the results of their experimentation. There are similar third-level concepts for 3.B and 3.C.

Figure 2. Draft of Unifying Theme Map for "Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons."



As a result of the work of the Commission, Review Panels, and College Readiness Products and Services Group, the AP Chemistry Course has been revised and redefined. The new AP Chemistry course is not intended to be a first formal opportunity to study chemistry. It bears reminding that learners construct their understanding of the world informally through their own experiences. Often, these explanations conflict with essential ideas within the discipline. Prior knowledge, skills, and abilities for taking an AP course have been identified, reviewed, and redefined. A draft of the topics not needed for understanding at the introductory level was also compiled, reviewed, and revised.

Also part of the AP Review were discussions regarding preconceptions and misconceptions that students are likely to bring to this course.

The first phase of the AP Chemistry Course and Exam Review was completed in 2007. Subsequent review panels were formed and convened to review and refine the initial work of the Commission. Once the review panels completed their work, the Curriculum Development and Assessment Committee supervises any additions and/or changes to the curriculum framework. This Committee also serves as the College Board's spokespersons, sharing this work with professional organizations, higher education faculty, and AP high school teachers alike. The new AP Chemistry course and exam will promote professional development opportunities, as well as provide updated classroom resources.

AP Chemistry Redesign Commission

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References

American Chemical Society. *Chemistry in the National Science Education Standards;* American Chemical Society: Washington, DC; 2003.

Conley, D. T. Advanced Placement Best Practices Study—Year 1. University of Oregon: Eugene, OR, 2006.

Lloyd, B.; Spencer, J. *New Directions for General Chemistry*. Division of Chemical Education with funding from the National Science Education. American Chemical Society: Washington, DC, 1994.

Mislevy, R. J.; Riconscente, M. M. (2005). *Evidence-Centered Assessment Design: Layers, Structures, and Terminology;* PADI Technical Report 9; SRI International: Menlo Park, CA, 2005.

National Research Council (NRC). *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools*. Center for Education, Division of

Social Sciences and Education. National Academies Press: Washington, DC, 2002.
NRC. *National Science Education Standards*. National Academies Press: Washington, DC, 1996.
Wiggins, G.; McTighe, J. *Understanding by Design;* Association for Supervision and Curriculum Development: Alexandria, VA, 1998.