# ACS and Its Role in the Future of Chemistry Education

***by Steven Long and Mary Kirchhoff***

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## Chemistry Education: Challenges and Opportunities

There is no shortage of experts when it comes to education. We have all been to school, and we know what worked for us—inspiring teachers, lots of homework, a rigorous curriculum, and caring parents. There is also no shortage of criticism when it comes to today's education system: teachers are poorly trained, students are lazy, classes are not challenging, and parents are too focused on their own careers to pay attention to their kids.

The challenge in education is that there is no single "right way" to do things. This is actually an opportunity though, as learning is a complex mixture of factors and a variety of approaches can be effective in meeting learning outcomes. The large number of variables involved in education presents a conundrum: how do we accurately assess what is effective in the classroom?

A tension exists in chemical education between covering traditional, in-depth content and introducing broader and more applied topics, such as industrial chemistry and sustainability. The "breadth vs. depth" argument is not new, but the increasing globalization of the chemical industry, the expanding multidisciplinary nature of science, and the growing emphasis on sustainability make a compelling case for change.

The American Chemical Society (ACS) directly supports the *National Science Education Standards* (National Research Council, 1996) in its *Statement on Science Education Policy* (American Chemical Society, 2007), and recommends implementing high standards:

> *Develop inquiry-based science curricula, based on content frameworks such as those provided by the National Science Education Standards (NSES) or AAAS Benchmarks, and include chemistry components at appropriate grade levels.*

The *National Science Education Standards* provide a framework for building a challenging science curriculum based on real-world interactions between students and the natural world. This chapter highlights some trends in chemistry education at the secondary and tertiary level, which influence the teaching of high school chemistry, and provides a snapshot of ACS resources that support the NSES.

## K–12 Curriculum

**Inquiry versus direct instruction.** Public education has provided moral, cultural, and educational stability in the United States by weathering political debates and pedagogical experiments. In the years since the National Research Council published the NSES calling for changes in K–12 science content and pedagogy, the changes have been steady, but slow. This inertia has been seen in the cautious adoption of the important reforms suggested in the NSES, including the greater emphasis on integrated instruction and inquiry activities. In the first edition of *Chemistry in the National Science Education Standards* (American Chemical Society, 1997), authors challenged readers to place less emphasis on isolated science content and cookbook activities, and place greater emphasis on integrated, problem-based and inquiry activities.

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Adoption of the NSES approaches is making inroads. There are successful programs in which teachers are experimenting with inquiry and integrated, problem-based content and in which students are experiencing the joy and satisfaction of "doing science." However, the change has been challenging because of the requisite retraining of in-service teachers, the redesign of preservice teacher preparation programs, and the inherent inertia of the educational system.

Momentum is growing, and educators should persist in their efforts to reform and improve K–12 chemistry education. Direct instruction, including lecture, is not wrong, but it may not be the best technique for all instruction, just as inquiry may not be the optimal method for all laboratory activities. However, students need the opportunity to experience chemistry as it is typically encountered in the scientific world: an open-ended problem or question involving multiple disciplines, without a clear-cut solution, and with multiple possible solutions.

**Diversity in student population.** Another challenge—and opportunity—for K–12 chemistry instruction is the increasing diversity of the students in the classroom. The homogeneity that was typical of many schools, even 25 years ago, is rapidly disappearing. The increase in diversity certainly includes ethnicity, but it encompasses much more. Students today are more diverse in almost every aspect, including their range of cultural experiences, family structure, religion, and interests.

A teacher 25 years ago could use a teaching analogy in class based upon a television show from the previous night. There were typically three or four network channels, and popular shows were easily identified. Today's teacher would find it difficult to do the same with more than 100 television channels, satellite broadcasts, and Internet programming. This is one simple example of the diverse classroom that teachers face today. Expand this diversity to include cultural, religious, family/social, and ethnic diversity, and it is easy to see why the pedagogical bag of tricks that were effective in years past may have diminished results today.

Furthermore, a student's socioeconomic class can strongly influence his or her interest in science and science-related topics. A student whose family is struggling to make ends meet may have less interest in the science of global warming than a student from a more affluent

background. Presenting examples that are contextually relevant to a diverse class engages students with the material in a more meaningful way but poses challenges for the teacher.

The increasing student diversity also represents opportunity. Students today need not fit into a predetermined mold. Instead of seeking jobs in the local area, students today compete in the global market. They know more, have greater access to knowledge and communication and will compete in the future for jobs that do not yet exist. Access to the Internet has widened the gap of knowledge and opportunity between the "haves" and the "have-nots". The opportunity is for students to capitalize on and create synergy from their diversity. Diversity can build strength and foster creativity; however, building this strength and creativity calls for innovation in the classroom on the part of educators.

The challenge of finding common experiences for effective instruction re-emphasizes the critical nature of the vertical alignment needed in science education. There must be a set of common science knowledge, skills, and activities that students have experienced upon which to build. The NSES provide a coherent backbone of content and skills if they are properly implemented. However, the quantity of knowledge and skills may need additional paring to distill it to a true common core. The educational debate over American education being an inch deep and a mile wide continues. (See chapter 13 for an expanded discussion on diversity in the chemistry classroom.)

**Role of AP and IB courses.** There is an increasing movement in the nation toward implementing Advanced Placement and International Baccalaureate programs (AP/IB). Schools seeking to prepare students for colleges and universities believe that the rigor of AP/IB courses is effective in propelling students into successful postsecondary studies. One recommendation emanating from the *Rising Above the Gathering Storm* report (The National Academies, 2007) focuses specifically on AP and IB courses:

> *Enlarge the pipeline of students who are prepared to enter college and graduate with a degree in science, engineering, or mathematics by increasing the number of students who pass AP and IB science and mathematics courses.*

AP and IB are the closest programs in the United States to providing a standardized national curriculum in chemistry. While there is great breadth of content and skills expected of students in either program, they are clearly defined for both the student and the teacher. The exams, projects, and scoring procedures allow the diverse student population to measure performance against each other and against a standard of excellence.

In addition, both AP and IB programs are recognized outside of the United States. The ability of students to attend college or university beyond our boundaries makes the AP/IB credits more valuable as students reduce global differences. Therefore, great care should be exercised in the design and the content of chemistry programs in both AP and IB. As secondary schools implement more AP/IB chemistry courses, there will be an increase in building Pre-AP and Pre-IB programs in middle and junior high schools to assure student success in the AP/IB courses. These Pre-AP and Pre-IB courses are intended to prepare every student, regardless of their background, to acquire the skills and knowledge to succeed in AP/IB chemistry. By default, the chemistry curriculum for many schools may be set by the College Board and the International Baccalaureate Organization. (See chapter 12 for a discussion of the redesign of the AP curriculum and exam.)

## Undergraduate Education

**Impact of globalization on professional preparation.** The Executive Summary of *International Education and Foreign Languages: Keys to Securing America's Future* (O'Connell and Norwood, 2007) opens with the statement "A pervasive lack of knowledge about foreign cultures and foreign languages threatens the security of the United States as well

as its ability to compete in the global marketplace and produce an informed citizenry." This observation is particularly relevant in light of the globalization of the chemical enterprise, a trend that suggests that today's students will be more likely to spend at least part of their careers working or doing business overseas. Consequently, it is increasingly important for students to have an international experience as part of their academic preparation (and to have studied a foreign language during the K–12 years). Science majors often have difficulty taking advantage of study abroad opportunities; however, this can disrupt the sequence of courses required for graduation, thereby prolonging time to degree.

International experiences for chemistry students are available and take a variety of forms. The new ACS-NSF-DAAD International Research Experience for Undergraduates program enables U.S. and German undergraduates to spend a summer conducting research in Germany and the United States, respectively. Some NSF-sponsored REU (Research Experiences for Undergraduates) programs, such as those offered by Syracuse University (Austria), the University of California, Santa Cruz (Thailand), and the University of Florida (France) are conducted overseas. Boston University takes another approach with the Dresden Science Program, designed for first-semester sophomores. Courses are taught in English (except for Intensive Beginning German, of course) and carry Boston University numbers, ensuring seamless transfer of credit. Students enrolled in the Dresden program take the courses they need in an international setting without disrupting the sequence of their major courses. Undergraduates benefit from these, and other, international opportunities, which serve to better prepare them for the global marketplace.

## Graduate Education

**Rise of interdisciplinary/multidisciplinary research.** Many of the breakthroughs in science occur at the boundaries of disciplines, and the titles of new journals—*ACS Chemical Biology, ACS Nano*—bear witness to the increasing interdisciplinary nature of chemistry. Graduate and postdoctoral students should not only be encouraged to pursue research at the interface of disparate disciplines, they should also be provided opportunities to explore these intersections in venues outside of research. For example, both the European Union and the United States host annual summer schools to introduce students to green chemistry concepts and applications. These programs provide in-depth exposure to green chemistry, a topic that is frequently missing from the education of our students, as well as opportunities to present research and establish new collaborations. Similar programs in other multidisciplinary areas, such as molecular biology and nanotechnology, would allow graduate students to expand their knowledge and explore new research collaborations in interfacial fields.

## Trends

**Competitiveness initiatives.** The alarm is sounding: Government leaders are concerned that the number of college graduates in science, technology, and engineering careers in the United States is declining. In chemistry, the 2005–2006 academic year actually saw record numbers of degrees awarded at both the undergraduate (11,938) and doctoral (2,321) levels. However, what is declining is the percentage of students earning degrees in technical fields, as more people are pursuing degrees in higher education. Furthermore, about one-third of Ph.D. graduates in chemistry are not U.S. citizens. As more attractive job opportunities open up in their native countries, these doctoral recipients are expected to return home in greater numbers, thereby creating a "brain drain" in the United States.

Both the U.S. government and American industries are concerned that the United States will lose its competitive edge in the world. Countries such as China and India are directing more resources to higher education in an effort to retain the best and brightest students. In addition, the off-shoring of high-quality, knowledge-intensive jobs in science and technology threatens

the foundation of the U.S. economy, national security, and quality of life. *Rising Above the Gathering Storm* clearly outlines the status of U.S. science and technology competitiveness and presents recommendations for education, research, and economic policy. While our lives are increasingly global as described in *The World Is Flat* (Friedman, 2005), we wish to maintain our competitive edge through science and technology to ensure our American way of life.

Mike Ciesielski

**Laboratory experiments, simulations, and online teaching tools.** The evolving world of technology creates opportunities to help students understand chemistry. Rather than draw diagrams of a chemical reaction on a chalkboard or wave colored polystyrene balls in the air, teachers can use three-dimensional computer animations to transform the complexity of reactions into powerful visual images. Instead of a static ball-and-stick model of a water molecule, students can see the convoluted motions of the molecule and its bonds as a type of chemical ballet. Demonstrations that are too expensive or dangerous for typical classroom use are easily pictured in videos.

Today's students have the resources to visualize chemical processes better than those in the past. Despite these advances in technology, however, experiencing chemistry in a hands-on setting in the laboratory remains an essential component of chemistry education. The National Science Teachers Association notes that "For science to be taught properly and effectively, labs must be an integral part of the science curriculum" (National Science Teachers Association, 2007). The ACS requires that undergraduate students complete 500 laboratory contact hours for an approved program (ACS Committee on Professional Training, 2003), thereby reflecting the centrality of the laboratory experience to the preparation of professional chemists.

Most high schools have a laboratory requirement for chemistry courses. These requirements typically range from 20 to 40% of instructional time. However, as safety issues and the costs of chemicals and equipment continue to increase, schools are beginning to look at alternatives to hands-on experiments, a move that raises a number of questions: Should all laboratory work be replaced with simulations and technology? What is the role of the laboratory experience in chemistry? Can students learn chemistry as well or better on a computer?

Unless technology advances to the point where students can realistically manipulate equipment (rather than point-and-click) and sense changes such as odor and temperature (rather than read descriptions or gauges), simulations and Internet resources must remain supplemental to the hands-on laboratory experience. Chemistry teachers should embrace and use technology for the strengths it provides, but not expect it to be a panacea. (Chapter 7 provides a detailed discussion of the use of technology in chemistry education.)

**Sustainability and green chemistry.** While green chemistry began with a focus on higher education, the introduction of green chemistry at the high school level offers several benefits. First, green chemistry laboratories offer improved safety by minimizing the use of hazardous substances. Second, implementing greener laboratory experiments can decrease the amount of waste generated, thereby decreasing waste disposal costs. Third, green chemistry demonstrates that chemistry can be practiced in an environmentally responsible manner, which reinforces the interest in environmental issues demonstrated by many students.

Although the term "green chemistry" was introduced about 15 years ago, green chemistry concepts have not been widely incorporated into the curriculum. This is not surprising, as new ideas typically take time to get integrated into the mainstream. In addition, several barriers to incorporating these concepts exist: a relative lack of curricular materials, an already

overcrowded curriculum, a perceived lack of rigor, and general inertia. Because inertia is a powerful force, a compelling case must be made for green chemistry, and the role of green chemistry in achieving sustainability makes a pretty strong case.

ACS collaborated with the Royal Society of Chemistry and the Gesellschaft Deutscher Chemiker to produce *Introduction to Green Chemistry* (Ryan and Tinnesand, 2002), a collection of six units that present key concepts in green chemistry. High school students are the target audience for this resource, which incorporates hands-on activities into the units, such as a Vitamin C clock reaction. The units in *Introduction to Green Chemistry* are aligned with the *National Science Education Standards.*

Additional curriculum materials continue to be developed. Several texts (Anastas and Warner, 1998; Clark and MacQuarrie, 2002; Lancaster, 2003) can be used for stand-alone green chemistry courses. Laboratory manuals (Doxsee and Hutchison, 2002; Kirchhoff and Ryan, 2002), primarily focused on organic chemistry, enable faculty members to introduce single experiments or an entire curriculum. The *Journal of Chemical Education* has published a number of green chemistry experiments through its "Topics in Green Chemistry" feature. Curricular materials are being disseminated through the University of Oregon's Greener Education Materials (GEMs) Web site (University of Oregon). This online resource allows educators to access, contribute, and review green chemistry curricular materials.

## The Role of ACS and Advocacy

State and local control of K–12 education limits ACS's direct influence on a national level: an approval process, equivalent to the ACS approval process at the undergraduate level, simply does not exist for high school chemistry. Nonetheless, the ACS, through its Office of Legislative and Government Affairs (OLGA), is a strong advocate with the federal government for K–12 science education. ACS and the National Science Teachers Association lead the STEM (Science, Technology, Engineering, and Mathematics) Coalition, which promotes the critical need for resources for "K–gray" science education. The opt-in Legislative Action Network (LAN) enables ACS members to communicate directly with their legislators on issues related to STEM education, as well as pending legislation in other areas of interest to the science community.

Where ACS does shape precollege education is through its resources, which enable science teachers to provide the best education possible. Online resources, high school chemistry clubs, textbooks, *ChemMatters,* conferences and workshops, and national recognition all contribute to the vibrancy of the discipline. The following sections highlight a few of these valuable resources.

**Chemical Education Digital Library.** An ongoing challenge for teachers in all disciplines is identifying (and finding) high-quality online teaching resources. Anyone can post anything online—how do you know it is from a trusted source? How do you know it will work in the classroom?

The National Science Foundation (NSF), through the National Science Digital Library (NSDL), offers a mechanism by which digital learning objects can be cataloged, compiled, and disseminated. NSF is supporting the development of the Chemical Education Digital Library (ChemEd DLib), an NSDL pathway project that will make it easier for educators at all levels to find useful, tested teaching materials and help create online communities focused on special interests.

**High school chemistry clubs.** High School Chemistry Clubs (ChemClubs) were initiated in 2005 to nurture the interest of high school students in chemistry. Currently, there are 120 ChemClubs chartered with ACS. These clubs receive a wealth of resources from ACS, including activities related to National Chemistry Week and Chemists Celebrate Earth Day.

ChemClubs are encouraged to network with their ACS Local Section and their local Student Affiliates Chapter, thereby creating a professional continuum from high school through retirement.

The three-year pilot of this program has seen a variety of activities on the part of the ChemClubs: chem demo shows for local elementary schools, field trips, fund-raising events for those affected by Hurricane Katrina, and National Chemistry Week events. These, and other, activities enable students to experience chemistry beyond the classroom, learn about further study and careers in chemistry, and provide service to their local communities. Information about ChemClubs, including how to start a club, is available online at www.acs.org/education.

**ACS textbooks.** ACS produced its first textbook, *Chemistry in the Community* (*ChemCom*), in 1988. This ground-breaking text (American Chemical Society, 2006*b*) for high school students introduced chemistry on a need-to-know basis, using environmental and health issues as the context for presenting basic chemistry information. The impetus behind this, and other, ACS textbook projects is to offer a different approach to the teaching of chemistry, one that differs from traditional textbooks. Subsequent ACS texts, *Chemistry in Context* (American Chemical Society, 2006*a*) and *Chemistry* (American Chemical Society, 2005), have followed the lead of *ChemCom* by presenting chemistry in the context of societal issues using a hands-on, inquiry-based approach.

**Professional development.** High school teachers are valuable contributors to the American Chemical Society. Numerous teachers mentor high school ChemClubs, engage their students in the Chemistry Olympiad, organize programming at ACS national and regional meetings, and develop curricular materials for use by the chemistry community at large. These activities strengthen chemistry education by reinforcing student interest in the central science and providing professional development opportunities for teachers.

Formal professional development opportunities for high school chemistry teachers are mainly offered by ACS through workshops centered on the use of the textbooks *Chemistry in the Community* and *Chemistry*. While *Chemistry* was developed for first-year undergraduates, a handful of high school teachers are using the text for AP and IB courses. This text offers several advantages over traditional general chemistry texts by focusing on active learning and placing a greater emphasis on the biological applications of chemistry. High school teacher-leaders run the textbook-based workshops, drawing on their experiences employing these texts in their own classrooms.

**Conferences and workshops.** ACS National and Regional Meetings provide an important venue for high school teachers to share best practices in the classroom. High School Teacher Day programming is now fully integrated into the technical program at ACS national meetings. The Biennial Conference on Chemical Education presents another opportunity for chemical educators to interact. ACS is well represented at ChemEd conferences and at the national and regional National Science Teachers Association conferences.

**Awards and recognition.** Excellence in high school teaching is recognized through the James Bryant Conant Award in High School Chemistry Teaching. The George C. Pimentel Award in Chemical Education honors the accomplishments of college and university faculty members. A new national award, the ACS Award for Achievement in Research for the Teaching and Learning of Chemistry, recognizes the importance of research in identifying best practices in chemical education. These awards highlight the accomplishments of extraordinary educators who make a difference in the lives of their students every day.

## Conclusion

We would all be fabulously wealthy if we could predict the future. We cannot. But we can anticipate the impact of trends in education and attempt to shape its future accordingly. More technology, increased multidisciplinarity, enhanced globalization, and a greater emphasis on standards are forces that are likely to continue to shape K–12 education, in general, and chemistry education, in particular. Exactly how these trends will play out is anybody's guess.

Louis Pasteur once noted that "In the field of observation, chance favors only the prepared mind." (Pasteur, 1854) While we cannot predict the future, we must anticipate the future, and preparing our minds for a multitude of options is our best chance for success. The American Chemical Society and its Education Division stand ready to partner with chemistry teachers to do just that.

### Recommended Reading

Singer, S. R.; Hilton, M. L.; Schweingruber, H. A. Eds. *America's Lab Report: Investigations in High School Science*; National Research Council, The National Academies Press: Washington, DC, 2005. This report is not very complimentary of the status quo of lab science teaching, but does identify strengths and weaknesses, and proposes actions to take. The emphasis is on coherent units of study in which hands-on science is integrated into the learning. The report is also available online at http://www.nap.edu/catalog/11311.html.

Lechtanski, V. L. *Inquiry-Based Experiments in Chemistry*; Oxford University Press: New York, NY, 2000. This book provides 35 inquiry experiments for first-year chemistry students, including the student directions, teacher's notes, and a sample lab report.

### Recommended Web Sites

The ACS Education Division offers a variety of education resources for students and teachers from kindergarten through graduate school. http://www.acs.org/education (accessed March 15, 2008).

The *Journal of Chemical Education* (JCE) provides resources that are relevant to educators in high school and higher education, including the JCE Digital Library. http://jchemed.chem.wisc.edu/ (accessed March 2008).

University of Oregon, Greener Education Materials. http://greenchem.uoregon.edu/gems.html (accessed March 15, 2008).

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