Development of Student Skills in a Chemistry Curriculum

It is a given that all students obtaining a certified degree in chemistry should be well trained in chemical concepts and laboratory practices. However, to be effective and productive scientists, students need to master a variety of skills that go beyond course content alone. These student skills, which are enumerated in the 2008 ACS Guidelines for undergraduate chemistry programs, are described below, along with comments on how they can be imparted and assessed within a chemistry curriculum.

Student Skills Defined

These skills, which can also be termed *process skills, soft skills, or employability skills*, share the characteristics that they are generic and transferable, are marketable and lifelong, and have wide applications that go beyond course content alone. Included in no particular order are the following:

Problem-Solving Skills

Chemistry education provides students with the tools to solve problems. This means that students should be able to apply the scientific method: define a problem clearly, develop testable hypotheses, design and execute experiments, analyze data, and draw appropriate conclusions. Assessment tools in chemistry courses should reflect this expectation. Examinations should be constructed to encourage the synthesis of a variety of concepts in solving problems while discouraging rote memorization. Students should be able to integrate knowledge across chemical subdisciplines and apply this knowledge to solve problems. In the laboratory, they should understand the use of statistical methods and the fundamental uncertainties in experimental measurements.

Chemical Literature Skills

Students should be able to retrieve specific information from the chemical literature and use the peer-reviewed scientific literature effectively. They should develop proficiency using Chemical Abstracts and other compilations. They should also be able to evaluate technical articles critically.

Laboratory Safety Skills

A high degree of safety awareness should begin with the first laboratory course and continue throughout a student's college career. This includes understanding safety and dress rules;

knowing when to use fume hoods; the use of safety/emergency equipment; handling, storage, and disposal of chemical waste; understanding and use of material safety data sheets; awareness of OSHA requirements; and, in general, knowing how to handle laboratory emergencies effectively.

Communication Skills

These skills, both written and oral, are among the most valued in chemistry graduates and least emphasized in many chemistry programs. At the same time, they are cited by industry as among those needing improvement in new graduates. Students should have a variety of writing experiences, not limited to laboratory reports. They should be able to synthesize information from a variety of sources in a clear and organized manner using a scientifically appropriate style. Equally important is the opportunity to present material orally. For the most effective experience, students should receive critical feedback on their oral or written communications. Students should be able to use communication technology such as computerized presentations as well as software for word processing, chemical-structure drawing, and poster preparation.

Team Skills

Solving scientific problems often involves working in teams, often in multidisciplinary teams. This is especially true in industry. Group experiences provide learning opportunities for students to appreciate how projects that capture the areas of particular expertise of the team members result in a stronger final product than would have been possible by independent work—the whole may be greater than the sum of its parts. Students should learn to work productively with a diverse group of peers; and should be able to lead portions of an activity or be effective followers, as dictated by the situation.

Ethics

Chemistry, like any discipline, has a social structure with a code of practices that govern acceptable/unacceptable behaviors. Progress in chemistry, as in all sciences, relies on complete honesty, openness, and trustworthiness of chemists, and on reproducibility of experimental results. Students should display high personal standards and integrity, conduct themselves responsibly, and be aware of contemporary issues related to chemistry.

Imparting and Assessing Student Skills

There are at least three modalities for imparting and assessing student skills: incorporation into existing courses throughout the curriculum; developing dedicated courses; and utilizing undergraduate research.

Using Existing Courses.

- It goes without saying that a culture of safety should be designed into all laboratory courses and the absolute importance of ethics should be incorporated into the instruction in all aspects of a chemistry curriculum.

- Course examinations can be used to encourage and assess problem-solving skills by asking the student to go beyond knowledge to demonstrate integration and utilization of information. Unless they are very carefully constructed, multiple-choice questions may not provide for the synthesis of a variety of concepts. Instructors should look for opportunities to use a variety of pedagogical tools, such as inquiry-based learning, projects that place experimental data in the context of the chemical literature, and take-home examinations.

- The chemistry curriculum should include writing and speaking opportunities beyond simply lab reports. The experience of finding and synthesizing information from a variety of sources in a term paper, with a critical evaluation of conflicting information, is invaluable training for a chemist. Similarly, preparing and delivering a talk or poster on a chemical topic can be incorporated into existing courses. Requiring the use of the primary and secondary literature in early chemistry courses will provide the foundation for student communication skills.

- Team projects can be introduced into existing courses. Examples include cooperative learning strategies such as organizing students into problem-solving teams in lecture courses or using team strategies in laboratory situations with each member responsible for defined activities. Peer-led team learning, using trained peer leaders who have completed the course, can also be effective.

Developing Dedicated Courses

- A chemical literature course can give students experience in oral and written communication of technical information beyond what may be available in general speech and English composition courses.

- A specific course in safety would have general applicability, but should not replace safety instruction specific to each laboratory course.

- A course in scientific and research ethics may be offered by the chemistry department or elsewhere in the college. A variety of resources and case studies for such a course are easily accessed on the Web.

- A capstone or seminar course for majors can provide an avenue to impart and assess student skills such as communication, chemical literature, and ethics.

Undergraduate Research

- Undergraduate research is one of the most powerful opportunities for students to learn problem-solving skills. "The quest to answer a question is where the learning takes place, not the answer itself." (R. N. Zare, C&EN, July 14, 2008, p. 3)

- Similarly, undergraduate research provides a unique opportunity for experience in oral and written communication. Both a written report and an oral presentation contain the expectation that a student will use the primary and secondary literature, will understand the context for the research, and can provide enough background to convey that to a reader or audience.

- Undergraduate research also provides students the opportunity to learn from their peers and solve problems in teams.

CPT Expectations

CPT expects that approved chemistry programs will have an established process by which they define, impart, and assess the development of student skills. The Committee will not look at individual student outcomes, but is interested in the process by which each program addresses the area of student skills.