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 described in the 2015 ACS Guidelines for undergraduate chemistry programs, are elaborated on 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 extend 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 using appropriate statistical methods, 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, in addition to the characteristics described above, students should understand the fundamental uncertainties in experimental measurements. Open-ended laboratory experiences provide excellent opportunities for the development and assessment of these skills.

Chemical Literature Skills

Students should be able to retrieve specific information from the chemical literature, critically evaluate technical articles, and manage many types of chemical information. Students should develop proficiency with electronic searching of appropriate technical databases, including structure-based searching. Student skills in this area should be developed and assessed in course work, laboratory work and upper-level capstone experiences including research projects. A separate supplement (available on the CPT website) provides additional information on chemical literature skills.

Laboratory Safety Skills

Programs must promote a safety-conscious culture in which students demonstrate and apply their understanding of the concepts of safe laboratory practices. 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; knowing when and how to use of safety/emergency equipment; handling, storage, and disposal of chemical waste; understanding and use of safety data sheets; and, in general, knowing how to effectively handle laboratory emergencies. Student attention to and knowledge of safety considerations should be evaluated in all instructional laboratory and research experiences. A separate supplement (available on the CPT website) provides additional information on laboratory safety.

Communication Skills

Written and oral communication skills are valued in chemistry 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 orally present material. For the most effective experiences, 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. A separate supplement (available on the CPT website) provides additional information on preparing a research report.

Team Skills

Solving scientific problems often involves working in disciplinary and multidisciplinary teams. This is especially true in industry and increasingly in academic settings. Group experiences provide opportunities for students to appreciate how projects that require contributions from team members with different areas of expertise often result in a better final product than would have been possible through independent work (i.e., the whole may be greater than the sum of the parts). Students should learn to work productively with a diverse group of peers in classroom and laboratory activities. Students should be able to lead portions of an activity or be effective followers, as dictated by the situation. Peer- and self-assessment is often an effective way to evaluate student contributions to group activities.

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 the chemist's complete honesty, openness, and trustworthiness, 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. A separate supplement (available on the CPT website) provides additional information on teaching professional ethics.

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 and implemented 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.

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. Formal presentations of their research to broader communities at program or institution-wide research forums or at regional or national conferences provide excellent motivation for students to develop their communication skills along with opportunities for students to exercise these skills.

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 throughout the curriculum. The Committee will not evaluate individual student outcomes but is interested in the process by which each program addresses the area of student skills.

CPT is also interested in how a program assesses student skills development and how the results of this self-assessment are used to modify the institution's curriculum and / or course materials.

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