

## Rigorous Undergraduate Chemistry Programs

The ACS approval program promotes the development of excellent undergraduate programs that, according to the ACS Guidelines, “offer their students a broad-based and rigorous chemistry education that provides them with the intellectual, experimental and communication skills necessary to become successful scientific professionals.” One hallmark of an excellent program is that it is rigorous. Articulating a clear description of what constitutes a “rigorous” program is challenging.

This supplement describes the qualities that CPT seeks as evidence for rigor in periodic reviews. A rigorous undergraduate program consists of an integrated series of experiences that evoke the systematic application of fundamental principles for the purpose of elucidating chemical phenomena and their interactions within systems. In evaluating undergraduate programs for rigor, CPT seeks evidence that certain attributes pervade the curriculum in student competencies, in faculty instructional approaches, and in the assessment of student learning. Some of these characteristics are described below.

### Characteristics of the Curriculum in Rigorous Undergraduate Programs

A rigorous undergraduate curriculum is one that provides foundation and in-depth course work that

- is appropriately balanced in breadth of content coverage and depth of treatment; and
- introduces students to an appropriately modern, quantitative, and mechanistic molecular perspective of the natural world.

Rigorous programs offer a breadth and diversity of courses, particularly at the in-depth level. Supplements that further articulate CPT expectations for coverage in different areas of chemistry are available on the CPT website (<http://www.acs.org/cpt>). Although it is impossible for CPT to consider the detailed content and course materials of every course in a given program in periodic reviews, CPT evaluates program attributes that serve as critical indicators of undergraduate curriculum rigor. The depth and sophistication of the textual material, including the use of primary literature, are proxy for rigor in foundation and in-depth courses. For in-depth courses, the syllabi and exams are evaluated for evidence of course rigor. CPT uses in-depth course rigor as an indication of the overall undergraduate program's rigor. The sophistication, depth, and overall quality of undergraduate research reports is one of the most important indicators of program rigor.

### Characteristics of Student Competencies in Rigorous Undergraduate Programs

A rigorous program develops students who are engaged in, and increasingly responsible for, their own learning. Students progressively develop throughout the curriculum the ability to

- search and utilize the primary literature;
- analyze data and scientific arguments;
- synthesize and apply concepts from multiple subdisciplines of chemistry;
- apply foundational and advanced concepts to new situations;
- solve multi-step complex problems; and
- communicate effectively in both written and oral forms.

Students in rigorous programs demonstrate an integrated view of chemistry, drawing upon appropriate quantitative reasoning and molecular mechanistic attributes of chemical processes.

In a rigorous laboratory course sequence, students

- progressively develop effective and safe chemical laboratory skills that require use of modern methods and instrumentation;
- start with simple stepwise manipulations performed according to a prescribed sequence and progress to open-ended activities that require decision-making about appropriate experimental design and data interpretation/analysis; and
- produce organized, concise, and coherent descriptions and analysis of their experimental work through written and oral reports.

Undergraduate research that culminates in a capstone activity is often a mark of a rigorous program. Such research experiences are those where students conduct original work and demonstrate

- mastery of independent thought;
- self-direction of activities; and
- application of an integrated, quantitative, and molecularly mechanistic view of chemistry.

Evidence for the development of student competencies is embodied in the complexity of tasks they undertake in classroom and laboratory course work and by the sophistication of their research activities. Through course work, students

- progressively develop the ability to use complex reasoning and higher-order problem solving skills beyond simple algorithmic problem solving and statements of declarative knowledge;
- demonstrate the ability to extend their conceptual understanding to chemical situations beyond those discussed in course work;
- produce written work that demonstrates clarity of thought, independent thinking, and sound scientific analysis and reasoning;
- hone data recording and organizational skills germane to laboratory work and the production of research reports; and
- develop an appreciation that chemistry is built upon, and advanced from, prior knowledge through effective use of the primary literature.

## Characteristics of Faculty Instructional Approaches in Rigorous Undergraduate Programs

The ability to offer a rigorous program depends on a competent faculty with modern disciplinary expertise in chemistry content and in effective practices in undergraduate chemistry instruction. Faculty should engage regularly in activities that sustain their vitality as professional chemists such as attendance at seminars, colloquia and professional meetings, and workshops, and should consult the primary chemical literature on a continual basis.

Rigorous instructional strategies in course work

- focus on creating learning environments that actively engage student participation;
- facilitate progressive development of student responsibility for learning throughout the curriculum;
- demand critical thinking and multi-step problem solving in daily activities;
- cultivate the development of an integrated understanding of chemistry throughout the curriculum;
- incorporate laboratory activities in which students define problems clearly, develop testable hypotheses, design and execute experiments, analyze data using appropriate statistical methods, understand the fundamental uncertainties in experimental measurements, and draw appropriate conclusions; and
- require regular faculty feedback on student work with attention to correctness, detailed commentary on language skills, and commentary on the precision and correct use of scientific language, chemical notation, and structural representation – all in alignment with accepted norms of the profession.

## Characteristics of Assessments in Rigorous Undergraduate Programs

CPT evaluates assessments of student learning, including exams provided by programs. Rigorous assessments are those that require students to demonstrate higher-order conceptual understanding and problem-solving skills. Rigorous exam formats include

- free response items, including structure drawing in organic chemistry;
- items requiring multi-step quantitative reasoning;
- items requiring demonstration of a mechanistic understanding of reaction pathways and chemical processes; and
- items that intellectually stretch students by requiring application of chemical concepts to new situations.

Exam items that require students to devise experiments to answer questions and that require articulation of chemical reasoning are excellent examples of rigorous assessment. Multiple-choice items can be one component of a rigorous exam, provided the questions elucidate more than simple declarative knowledge. In general, CPT expects that rigorous assessments, especially those for in-depth courses, will rely minimally on multiple choice-based questions. In addition to faculty-formulated exams, programs may also wish to consider using standardized ACS exams for assessment (<http://chemexams.chem.iastate.edu/>). Although ACS exams have multiple-choice questions, they do provide a useful vehicle for national, normative-based assessment of student learning.

## Strategies for Improvement of Program Rigor

Since appropriate rigor is a critical metric for ACS approval of an undergraduate chemistry program, programs should routinely assess the rigor of their undergraduate chemistry offerings. Should programs wish to improve further the rigor of their curriculum, several strategies might be employed. Programs are encouraged to

- consult with colleagues at institutions of comparable size and mission, particularly those with excellent reputations for the production of well-educated undergraduates;
- consult the literature in chemical education for insight into rigorous and modern presentations of chemistry at the undergraduate level; and
- invite well-respected and knowledgeable chemists to consult on issues of undergraduate program rigor.

Appropriate rigor in an undergraduate program is possible through careful attention to the programmatic details articulated above and by maintaining a watchful eye on modern developments in chemistry and chemical education.

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