

Building the ACS Exams Anchoring Concept Content Map for Undergraduate Chemistry

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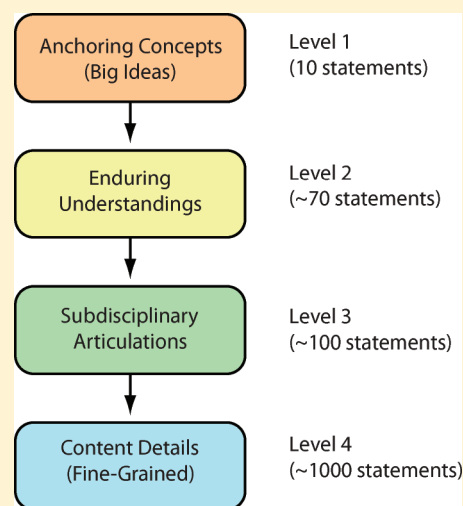
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ABSTRACT: The ability to coherently assess content knowledge throughout an entire undergraduate career represents a significant advantage for programmatic assessment strategies. Chemistry, as a discipline, has an unusual tool in this regard because of the nationally standardized exams from the ACS Exams Institute. These exams are norm-referenced and allow chemistry departments to make comparisons between the performance of their own students relative to national samples; however, currently there appears to be no systematic means for noting students' content knowledge growth over a four-year degree. The Exams Institute is undertaking the task of organizing content along an anchoring concept or "big ideas" framework to facilitate this type of analysis.

KEYWORDS: First-Year Undergraduate/General, Second-Year Undergraduate, Upper-Division Undergraduate, Interdisciplinary/Multidisciplinary, Testing/Assessment



The demand for improved assessment in education has increasingly touched all levels of instruction, including college courses. While the general reaction of college faculty lacks enthusiasm for demands of accountability based on assessment, there are ample indicators that enhanced assessment is quite likely. At the national policy level, the Spelling Commission Report is explicit in its calls for more assessment data about teaching and learning efficacy.¹ At an institutional level, the calls for accountability have largely been addressed via voluntary mechanisms.² While there are assessments that are conducted at the institutional levels, ultimately, many college instructors are facing new demands for enhanced assessment efforts.

For college chemistry faculty members, this demand is not only from institutional accreditation, but also from departmental efforts to address reporting expectations from the Committee on Professional Training (CPT) of the American Chemical Society (ACS), which approves programs that award chemistry degrees. These guidelines have increased the emphasis on measuring outcomes of learning in chemistry courses. While there are many ways to carry out outcomes-based assessment³ (OBA), chemistry also holds the unique position within academia of having established and maintained

the ACS Examinations Institute (ACS-EI), which has produced standardized tests for over 75 years. This paper describes efforts taken by ACS-EI to improve the ability to use the ACS Exams to address outcomes-based programmatic assessment.

The key feature that arises for college education relative to OBA is that there is no external agency, government or professional, that establishes standards for student learning. Thus, departments that seek to adopt an OBA regime often require their faculty to invest substantial time devising a local set of standards themselves. Having a content map of the undergraduate chemistry curriculum to which ACS Exams are aligned can assist these local efforts, both in terms of basing the OBA on an external metric and in terms of accessing assessment tools (ACS Exams), to obtain information. This paper presents the methodology for the development of such a content map in chemistry.

■ PROCESS AND LITERATURE REVIEW

The ACS Exams Institute has no authority to establish actual standards for content in chemistry and does not seek to accrue

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Table 1. Meeting Schedule of Workshops and Focus Groups for Creating the ACS Exams Institute Content Map

Meeting or Conference	Subdiscipline	Date	Focus Group
ACS National Meeting	NA	March 2008	Level 1 and 2 synthesis
Biennial Conference on Chemical Education	General Chemistry	July 2008	Level 3 synthesis (General Chemistry) Testing and refinement (General Chemistry map)
ACS National Meeting	General and Organic Chemistry	March 2009	Level 4 selection and synthesis (General Chemistry) Testing and refinement (General Chemistry map) Level 3 synthesis (Organic Chemistry)
ACS National Meeting	General and Organic Chemistry	August 2009	Testing and refinement (General Chemistry map) Level 3 synthesis and refinement (Organic Chemistry)
ACS Regional Meeting (NERM)	General Chemistry	October 2009	Testing and refinement (General Chemistry map)
ACS National Meeting	General, Organic, and Physical Chemistry	March 2010	Testing and refinement (General Chemistry map, now using first- and second-term General Chemistry exam items) Testing and refinement (Organic Chemistry map) Level 3 synthesis (Physical Chemistry)
ACS National Meeting	General Chemistry	August 2010	Testing and refinement (General Chemistry map, now using first- and second-term General Chemistry exam items)
ACS Regional Meeting (combined SWRM and SERMACS)	Organic Chemistry	December 2010	Testing and refinement (Organic Chemistry map)
ACS National Meeting	Analytical, Physical, and Biochemistry	March 2011	Level 2 refinement and Level 3 synthesis and refinement
ACS National Meeting	Analytical Chemistry	August 2011	Level 3 refinement

such authority. ACS-EI has always used a “grassroots” approach to test development, with content coverage being established by committees of instructors who teach the course for which a particular exam is being developed.⁴ This circumstance does not exclude using what has been learned in more formal standard setting contexts to guide the effort to establish a content map for undergraduate chemistry.

Standard setting has been the focus of research in educational measurement for decades.^{5–8} One key concept that emerges from this work is that of using a participatory process.⁹ In this sense, the role of various stakeholders is emphasized. In the case of ACS-EI, the apparent stakeholders include (i) those involved in the broader educational effort of the ACS; (ii) the volunteer chemical educators who serve in the test development process; and (iii) the user base of educators who purchase ACS Exams and test their students with them. The process by which the ACS-EI content map was developed explicitly incorporates input from this set of stakeholders.

The starting point for the map creation process represents the most important connection to the broader ACS educational endeavor. The “big ideas” format that the map assumes was first discussed, and putative big ideas were first established at a conference held by the ACS Society Committee on Education (SOCED), called Exploring the Molecular Vision (EMV).¹⁰ Thus, the ACS-EI began its process of building the content map using results from the larger ACS community. The second set of stakeholders, volunteers who work on ACS-EI test development, also played a critical role in several steps of the map production process. Most importantly, focus-group style workshops were held with groups of educators from test development committees at several conferences, including ACS National Meetings and the Biennial Conference on Chemical Education. These groups provided suggestions at every level of the content map. Finally, the broader chemistry education community has also been involved in focus-group refinement of the content map. Sessions held at both National and Regional Meetings of the ACS have provided opportunities for comments and suggestions related to the map. It is anticipated that this type of revision will continue into the future; and that

the map presented in the adjoining article,¹¹ while revised many times, is going to continue to be vetted by the community in such workshop settings.

In addition to building on the process aspects of standards setting, the content map version created by ACS-EI also builds on the terminology of evidence-centered design (ECD)¹² or its precursor, backward design.¹³ Thus, the content map developed uses a “big ideas” framework rather than one that is subdisciplinary based. In ECD, the top level of the content map is a set of big ideas that are then described in terms of a set of “enduring understandings”, concepts that represent the most critical, foundational aspects of that idea. At least through the top two levels of the ACS-EI content map, this language has been adopted. The ultimate goals of designing assessments and then curricula that are inherent in ECD are not part of this effort, however.

The initial set of big ideas was derived, as noted earlier, from the EMV conference. In the first set of focus groups to elucidate potential enduring understandings, it became clear that some additional big ideas would be required relative to those proposed at the EMV conference. The creation of these important, top two levels of the content map, therefore, was ultimately vetted through several workshops. All subsequent workshops also allowed for comments on the top two levels, even when the primary focus of the efforts was at the finer-grained statements than these two top levels.

Table 1 presents the timeline of workshops that have been held thus far to elicit comments from various stakeholders in the process. As noted below, the anchoring concept content map (ACCM) consists of four levels with increasingly fine granularity of the concepts that are incorporated, and this granularity is captured in the table by designating the level. For example, the coarsest grain is level 1: the anchoring concepts or big ideas. In between workshops, the many and varied comments of participants were synthesized and the content map revised by the ACS-EI.

On the basis of the timeline inherent in this table, progress on the various subdisciplines in this process is varied. Ultimately, all traditional fields within chemistry, including

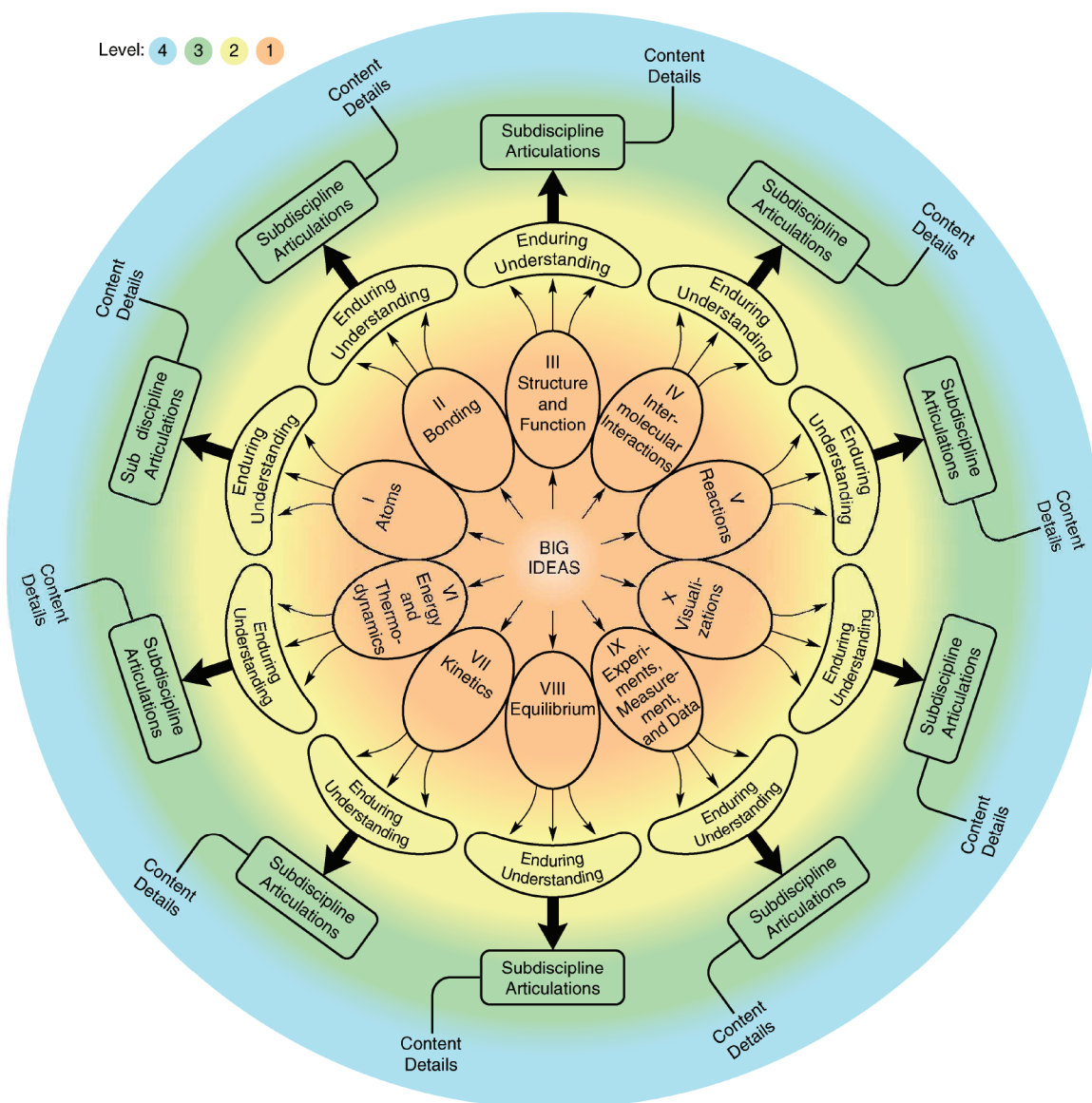


Figure 1. Schematic depiction of the levels of the anchoring concept content map (ACCM). The 10 big ideas at the center are the coarsest-grained depiction of chemistry (level 1). They connect to slightly finer-grained ideas called enduring understandings, which define the most important features of the big ideas (level 2). Enduring understandings are then articulated for subdisciplines in chemistry (level 3 in “pill boxes”), and finally the content details of courses in chemistry compose the final, fine-grained level (level 4) of the ACCM content.

inorganic chemistry, which has not yet begun the process, will be included. The content map that has arisen from this process represents the first stage in the ability to use ACS exams in terms of outcomes-based assessment programs. In addition to this variable, the ACS-EI is simultaneously establishing the ability to assign additional performance-related variables to items within the exam. Thus, the establishment of a rubric for assigning the cognitive complexity of a test item has recently been discussed elsewhere.¹⁴ The combination of content and complexity is then used in alignment studies,¹⁵ and preliminary alignment work has also been carried out as part of the process to refine the content map. These alignment workshops were carried out with focus groups in the same meeting sites as noted in Table 1. Results of the initial alignment work for two general chemistry exams are provided in this work to illustrate the process further.

Finally, it is worth noting that this effort is taking place within a larger context in which such content map activities are

occurring more broadly. While aimed at K–12 education, the recently released National Research Council report¹⁶ *A Framework for K–12 Science Education: Practices, Cross-Cutting Concepts and Core Ideas*, represents perhaps the most comprehensive example of this form of content mapping. At the same time, The College Board has been undertaking an extensive content mapping project aimed at revising the nature of advanced placement (AP) exams,^{17,18} including chemistry.¹⁹ It is also worth noting that a community of biochemistry educators has proposed a “big ideas” map for that topic.²⁰

■ THE CONTENT MAP STRUCTURE AND USE

The unique feature of the ACS-EI content map lies in the manner in which it is designed to span the entire undergraduate curriculum. It is predicated on a big-ideas template and ultimately includes four levels of description of the undergraduate content. Figure 1 depicts these levels schematically. Notably, Figure 1 does not attempt to depict the granularity of

the levels. There are typically 5–8 enduring understandings, and similar numbers of subdisciplinary articulations. A static visual depiction that captures this level of detail becomes hopelessly complex.

The “top” level (level 1), drawn in the center of the figure is called the “big idea”, or anchoring concept portion of the map. The circles represent concepts that are important in chemistry and are generally covered in some fashion in virtually every course. The 10 anchoring concepts that comprise level 1 of the content map are presented with more detail in Table 2. The

Table 2. The Anchoring Concepts of the Anchoring Concepts Content Map

“Big Idea” Title ^a	Anchoring Concept ^b
I. Atoms	Matter consists of atoms that have internal structures that dictate their chemical and physical behavior
II. Bonding	Atoms interact via electrostatic forces to form chemical bonds
III. Structure/Function	Chemical compounds have geometric structures that influence their chemical and physical behaviors
IV. Intermolecular Interactions	Intermolecular forces—electrostatic forces between molecules—dictate the physical behavior of matter
V. Chemical Reactions	Matter changes, forming products that have new chemical and physical properties
VI. Energy and Thermodynamics	Energy is the key currency of chemical reactions in molecular-scale systems as well as macroscopic systems
VII. Kinetics	Chemical changes have a time scale over which they occur
VIII. Equilibrium	All chemical changes are, in principle, reversible; chemical processes often reach a state of dynamic equilibrium
IX. Experiments, Measurement, and Data	Chemistry is generally advanced via experimental observation
X. Visualization	Chemistry constructs meaning interchangeably at the particulate and macroscopic levels

^aThese titles correspond to the level 1 big idea labels used in Figure 1.

^bThese concepts correspond to the level 2 enduring understandings provided in the online supporting information for ref 11.

premise of this content map is that the 10 anchoring concepts are typically covered in some way in most courses. Although courses may not be organized with these concepts in mind, they are part and parcel of most courses.

The second level depicts enduring understandings, foundational concepts that underpin all of the content that might be included within a specific anchoring concept. One view of enduring understandings is that they represent the key, basic ideas that an instructor would hope a student would remember about the topic, having had courses in chemistry. The level-2 enduring understandings are designed to span all the subdisciplines of chemistry, and thus an additional level that allows instructors to identify how a particular subdiscipline or even a specific course addresses the enduring understandings is included as level 3 in the map. Including this level in the map provides an important step, both from the perspective of stakeholder buy-in, and also for envisioning ways to use the map for analysis purposes. The level-3 subdisciplinary articulations, therefore, provide the first level that addresses how the level-2 understandings are included into the courses within a subdiscipline. This level also provides the basis for the final level, level 4, which includes fine-grained details of course content. Most exam items are written with this level of content in mind, so this level is important in the subsequent alignment

work that takes place to identify where exam items are mapped within this depiction of chemistry content.

The most important component of this structure lies in the fact that the top two levels of ACCM do not change throughout the undergraduate curriculum. Departments may, therefore, identify learning objectives that span the curriculum longitudinally, and have the ability to use ACS Exams and have an externally referenced content knowledge assessment as part of their plan.

Departments can also use this structure to examine content coverage of particular courses or subdisciplines within their program. Similarly, this structure can be used to examine students’ content knowledge within a specific big idea as it spans courses through the program.

Figure 2 shows this concept schematically for a subset of a single big idea in the hypothetical case where a department uses ACS Exams in four courses: general chemistry, analytical chemistry, organic chemistry, and physical chemistry. Each course has (or will have when the process has been completed) a set of subdisciplinary articulations. ACS Exam items for the four tests are aligned so that instructors know which content (in this example about reactions) is tested on each exam. Thus, information is obtained in each course (level 3, in green) and ultimately in a longitudinal sense at levels 2 and 1 (yellow and red).

Consider as a less schematic example, a department that identifies student understanding of chemical reactions as a key content area that they will measure for contributing data to campus-mandated assessment efforts. Reactions are the topic of anchoring concept V, and in Figure 2, all four exams include items that measure student content knowledge about reactions. The faculty of this department could then track student performance on items that align under anchoring concept V and have snapshots of the content knowledge at several junctures in the undergraduate course of study. This information could be collated in several ways. First, overall student performance on items related to chemical reaction could be estimated in terms of the fraction of correct answers on those items. This level of analysis could be further augmented by determining whether that fraction of correct answers changes as student progress through the curriculum (and take tests with more sophisticated treatments of reactions). Also, because ACS Exams are also norm-referenced, the department could assess student performance on items about chemical reactions as compared to national performance levels on those items. Finally, the department may be particularly interested in some aspect of chemical reactions that corresponds to a subset of the enduring understandings that have been identified for anchoring concept V. This level of analysis will ultimately have fewer items from which to draw inferences, but enduring understandings span the whole curriculum, so the analysis can certainly be carried out, at least over a cohort of students.

This form of utility requires the item alignment process to occur for all ACS Exams. This process has been initiated for general chemistry content, and initial results suggest interesting patterns, as noted in Figure 3. Because of the size of the ACCM, Figure 3 cannot capture the wording of the enduring understandings themselves; however, this information is available in the online supporting information of the accompanying article, which presents the details of the ACCM for General Chemistry.¹¹ Even without this detail, the

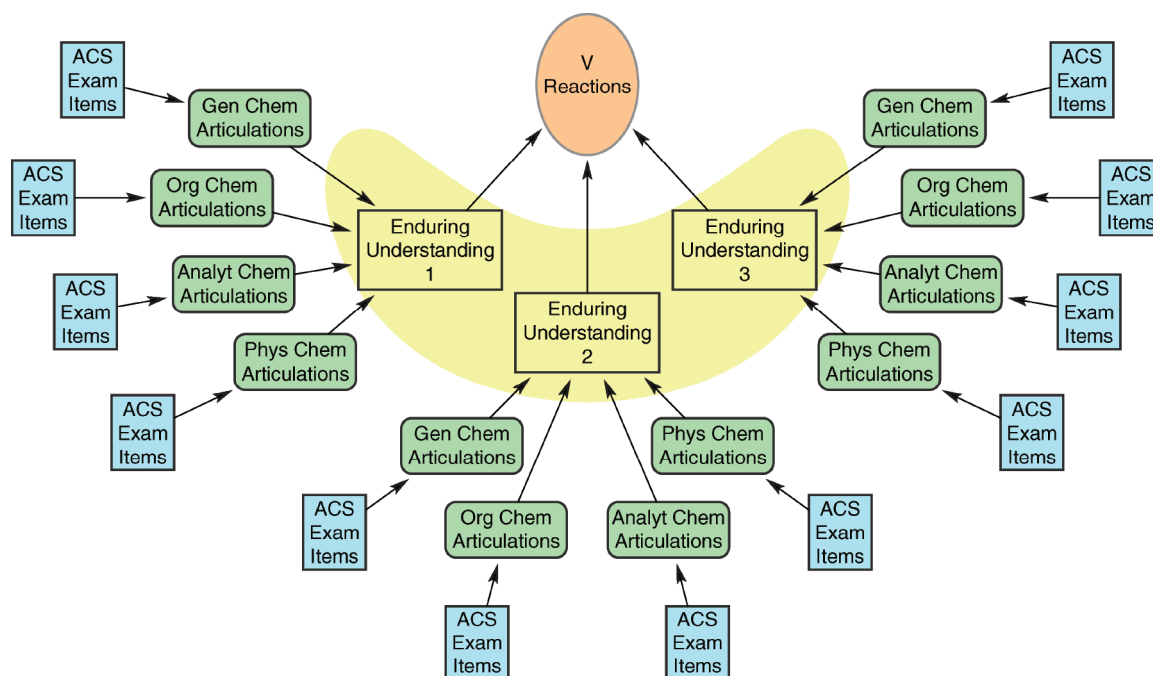


Figure 2. Depiction of longitudinal usage of the anchoring concepts content map (ACCM). All items are aligned to statements in the subdisciplinary articulation (level 3), so enduring understandings (level 2) and big ideas (level 1) are constant across the curriculum.

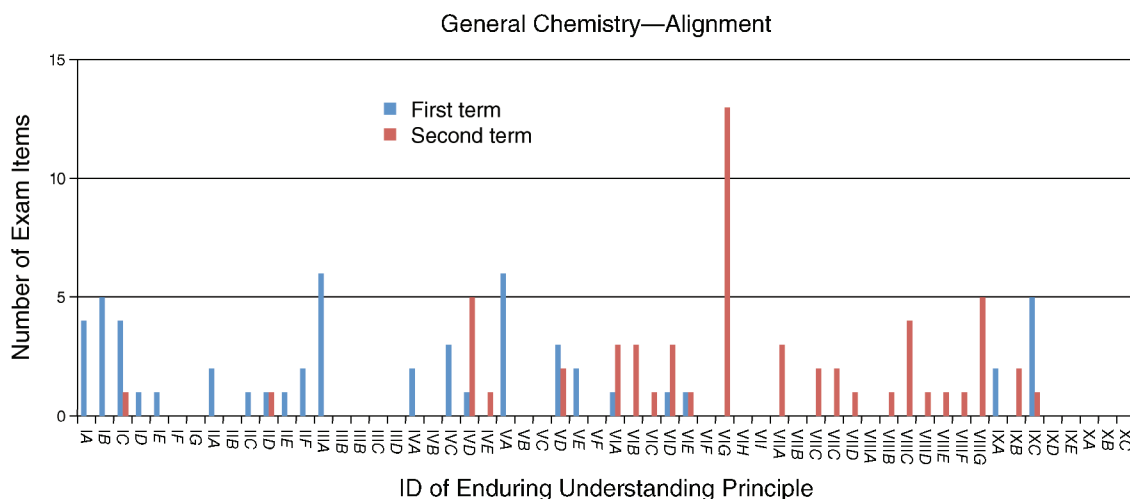


Figure 3. Item counts for enduring understandings present in ACS General Chemistry exams. Blue indicates first-term exams and red indicates second-term exams. The roman numerals and letters designate each enduring understanding (with the roman numeral indicating the anchoring concept as defined in Table 2) in the ACCM. The full list is available in the online supporting information that accompanies ref 11.

figure provides immediate visual evidence about the nature of content coverage in general chemistry.

The alignment itself was completed by general chemistry instructors who are primarily from the second group of stakeholders, users of ACS exams, and therefore familiar with ACS exam items. This alignment was conducted independently with approximately 20–30 min of instruction and practice. For an item to be included in this data set, the majority of the raters needed to agree on the placement of the item (at least to level 2 of the ACCM). Following the alignment, there was a group discussion on the process but not a subsequent discussion on moving items in order to achieve any higher level of rater agreement. The raters placed with agreement 55 items and 58 items for the first- and second-term general chemistry exams, respectively. The first observation is that, perhaps unsurprisingly,

ingly, many areas of the ACCM include at least some items from a pair of general chemistry exams (one first-term exam and one second-term exam). It is also clear that some topics (such as equilibrium) appear almost exclusively in the second term, and others (such as atomic theory) are concentrated in the first term of the course. This level of empirical categorization reflects the current state of curricular design in general chemistry.

This type of analysis can lead to important discussions on curriculum or assessment design, especially when missing coverage or overcoverage is revealed through an alignment process. Similarly, it is expected that this structure could be used to align locally developed assessments seeking similar information and can be used to compare to ACS Exams for measuring content knowledge within a program or course. It is

also important to note that these results show only a portion of the alignment, placing the items on the content variable only. The full alignment also includes a complexity variable; both of these variables combine to provide information on students' content knowledge and, through comparison, the growth in this content knowledge.

As this alignment process proceeds, it will also provide useful information for the test development committees of ACS Exams.⁴ While the grassroots organization, where the committee decides the content coverage of each exam, will not be eliminated, it is expected that having more data about how ACS Exams align to the ACCM will ultimately have some impact on how future exams adjust their content coverage. Thus, even for the ACS-EI, the long-term influence of the availability of the ACCM is likely to be important.

SUMMARY

The construction of a broad, big-ideas-based content map is described, with specific content descriptions for general chemistry included. The goal of this project is to allow users of ACS Exams to be able to devise outcomes-based analyses of student learning as measured by these tests. The exams will continue to be norm-referenced as well, so departments that use ACS Exams will be able to compare students to both national samples and to specific content domains within chemistry. This capacity can assist departments in meeting new demands for assessment that arises from external sources, such as university accreditation.

The content map in its current form has been established with input from participants of several sessions of workshops and focus groups. ACCM has achieved a level of stability in the top two levels for most of the undergraduate curriculum. Nonetheless, it is expected that it will undergo continuous change, and feedback mechanisms for users to make suggestions will be available through the ACS-EI Web site²¹ to facilitate such input. The detailed content within the ACCM will be published elsewhere,¹¹ because of the overall length of the descriptions contained therein.

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Notes

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