

What Do Conceptual Holes in Assessment Say about the Topics We Teach in General Chemistry?

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ABSTRACT: Introductory chemistry has long been considered a service course by various departments that entrust chemistry departments with teaching their students. As a result, most introductory courses include a majority of students who are not chemistry majors, and many are health and science related majors who are required to take chemistry. To identify content areas that are either well covered or sparsely covered, approximately 2000 exam items from four types of General Chemistry ACS exams (Full Year General Chemistry, General Chemistry Conceptual, First Term General Chemistry, and Second Term General Chemistry) spanning two decades were aligned to the Anchoring Concepts Content Map (ACCM). ACS exams were chosen as artifacts due to the nature of the exam development by committees consisting of chemists who are experts in the field. The ACCM is developed such that the statements from the first two levels are stable across the entire undergraduate chemistry curriculum, while the third and fourth levels are subdiscipline specific. It was found that there are 17 statements at the second level (Enduring Understanding) that have rarely been assessed on General Chemistry ACS exams over the past 20 years. Some of these topics appear in areas that are likely important for students whose interest lies in the life sciences, including no items testing the concept of intermolecular forces in the context of large molecules. These results suggest that chemistry curriculum reform efforts may benefit from considering specifics of content domain coverage.

KEYWORDS: First-Year Undergraduate/General, Testing/Assessment, Curriculum

Intermolecular Interactions	In	Out
weaker than chemical bonds	<input checked="" type="checkbox"/>	<input type="checkbox"/>
non-covalent in large molecules	<input type="checkbox"/>	<input checked="" type="checkbox"/>
categories of interactions	<input checked="" type="checkbox"/>	<input type="checkbox"/>
physical properties	<input checked="" type="checkbox"/>	<input type="checkbox"/>
reactions in solution include	<input type="checkbox"/>	<input checked="" type="checkbox"/>

INTRODUCTION

Chemistry departments typically offer chemistry classes for students who wish to enter careers in a variety of areas such as medicine, biology, engineering, and physics. Other areas of science tend to send their students to general chemistry for their students to learn the fundamental chemistry behind what the student will be studying in the other disciplines. As such, introductory chemistry has long been considered an important “service” course for chemistry departments, one that bolsters teaching resources because of its large enrollments. Biology faculty reported that their students need to understand the fundamentals behind covalent bonding, noncovalent interactions, bond rotations and vibrations, and dynamic aspects of molecular structure for them to fully understand the biology.¹

Because chemistry is considered an important entry-level course for many science and health related majors, it is often viewed as a key gateway course for aspiring science majors. In light of this curricular role, if the needs of the departments sending their students to take general chemistry courses from the chemistry department are not being met, it is conceivable that these client departments could demand changes. Given the important service component of the general chemistry course, the question needs to be asked if chemistry departments are meeting the needs of life sciences students and other science departments through the content taught in general chemistry.

The American Chemical Society Exams Institute (ACS-EI), which is an activity of the Division of Chemical Education (DivCHED), has developed a series of standardized exams for

each subdivision of chemistry that can be used to assess the level of understanding of their students. In general chemistry, there are several types of exams that instructors or institutions may select for assessment. Each exam is developed through the work of committees that are formed for the purpose of exam development.² Each proposed item is trial tested in classrooms and selected based on item performance for use in the final version of the exam. The final standardized exams are used by many universities to assess the level of understanding of their students. The process for test development allows each exam to be used as a historical artifact reflecting current topics taught in chemistry classrooms.³

EXAM ITEMS AS ARTIFACTS

The grassroots process, used to develop ACS exams, captures the content being taught in schools across the United States. Exam content coverage is not established by a governing body but rather reflects the classroom experience of the members of the exam development committee. Content that appears on a released version of an ACS General Chemistry exam has been proposed by instructors in the course and validated by student performance metrics obtained during trial testing. Therefore, this process insures that items on ACS exams provide insight into the content domain coverage of a large percentage of general chemistry courses.

To assess what concepts have been historically covered in the general chemistry curriculum, a database was built from four different types of ACS General Chemistry exams that have each been released several times in the past 20 years: General Chemistry (GC) exams that cover the full year, General Chemistry Conceptual (GCC) exams, First Term General Chemistry (GCF) exams, and Second Term General Chemistry (GCS) exams.⁴ As part of the development of the database, each exam item was aligned to the “Anchoring Concepts Content Map” that has been developed and refined by ACS-EI for General Chemistry (ACCM-GC).^{5–7} This mapping of test items can be used to determine what content has been strongly emphasized and what content has not been included on the ACS exams over the past two decades. The GC exam is released biannually, and the GCF exam is released every two or three years, so the database contains 785 GC exam items and 715 GCF exam items, respectively. The GCC exam was first released in 1996 and has since been released two additional times for a total of 200 GCC exam items. There have been four GCS exams released in the past 20 years with 295 items total.

■ DEMOGRAPHICS OF GENERAL CHEMISTRY COURSES

Beyond the development process of ACS exams, the other key component of this effort lies in the collection of data for national norms. This process is voluntary, and exams are ultimately sold to many more schools than participate in the normal data collection process. Nonetheless, as part of that process, the ACS-EI asks instructors to report several demographic details including the majors of the students in their courses. This reporting process, therefore, provides a sampling of national trends in student interests among those who have taken an ACS exam. The most reliable data from this process for the General Chemistry exams come from 2000–2012. In this time period, faculty reported students’ majors for 11,521 students who took ACS General Chemistry exams. Estimates obtained from these demographics reports indicate that only 10.9% of the chemistry students were chemistry or chemistry engineering students, while 67.3% of the students were from other sciences, premed, nursing, or agriculture majors. This observation is roughly in line with a recent study from Brandriet and Bretz who found via the national implementation of a concept inventory for redox chemistry that approximately 53% of the students reported were life science majors or applied science majors.⁸

■ ANCHORING CONCEPTS CONTENT MAP

The ACS-EI undertook the ACCM project to provide a way to more clearly identify the content domain coverage of chemistry tests across the undergraduate curriculum. A key motivation for this project was the need to provide resources for program assessment.⁹ A needs analysis conducted by ACS-EI suggested that most departmental assessment efforts are externally motivated.^{10,11} The development of the ACCM was therefore designed to benefit chemistry educators by providing an organizational scheme that will allow chemistry departments to analyze what content students are being assessed on throughout the undergraduate curriculum.

The ACCM is designed to organize the content taught at each level of chemistry, so the form of the map uses a structure that frames content along “anchoring concepts”. Thus, at each level of the curriculum, content is described in terms of

statements that range from the most coarse grained understanding (Level 1 Anchoring Concepts or “Big Idea” Statements) to the most fine grained content detail statements (Level 4).^{6,7} Each level 1, big idea statement is then divided into statements that represent students enduring understanding (Level 2 of the ACCM). In each area of chemistry, a separate map is being developed that identifies key aspects of the level 1 and 2 statements that are covered in courses in that area and articulates them as level 3 statements about subdisciplines. Finally, level 4 statements are devised, which contain content details as normally contained in textbooks and course syllabi for that subdiscipline. The General Chemistry map (ACCM-GC) was first released in 2012,⁶ and a revised, second version of the ACCM-GC has recently been completed.^{4,7} On the updated version of the ACCM-GC, the overall distribution of statements showed that the map is fairly balanced in the treatment of content across the range of 10 anchoring concepts.⁷

Even with the general balance in the ACCM-GC, there are fewer level 4 statements in the anchoring concept dubbed “visualization” than in other areas of the map. There were also a larger number of level 4 statements for the anchoring concept on “atoms” and the anchoring concept on “experiments”, so it can be predicted that any analysis of item content will be sensitive to the differences in the number of statements beneath any given anchoring concept. Because these structural differences play a role in the analysis of content as presented here, the statement structure of the ACCM-GC is provided in Table 1.

Table 1. Distribution of Statements Across the General Chemistry Anchoring Concepts Content Map (ACCM)

Level 1 Statements (Big Ideas)		Number of Statements on the ACCM		
		Level 2	Level 3	Level 4
1	Atoms	7	19	41
2	Bonding	7	13	21
3	Structure	9	12	23
4	IMF	5	10	28
5	Reactions	7	13	27
6	Energy	9	19	31
7	Kinetics	6	12	21
8	Equilibrium	7	13	24
9	Experiments	8	22	36
10	Visualization	5	8	11
All 10 big ideas		70	141	263

It is important to note that the ACCM was constructed to over specify the possible content of any course. This was done so that (i) the entire set of the maps in all subdisciplines would be complete and (ii) so that test development committees for ACS exams would not perceive a constraint in content coverage.

■ OVERALL EXAM CONTENT

On the ACCM, there are 10 big idea statements that cover content not only on topics such as atoms and bonding, but also experimental content and visualization. In so far as the appearance of test items on ACS exams represents an artifact of the general chemistry courses, an analysis of where these items fall in the ACCM-GC provides insight into content coverage tendencies for general chemistry. Distribution of items

from the past 20 years of ACS exams into the 10 big ideas was determined via the alignment process previously reported.⁴ A group of five raters determined content alignments, and this process showed that the items were not evenly distributed across the ACCM map (Figure 1) despite the fairly even

Distribution of questions across each of the Four types of general chemistry ACS exams

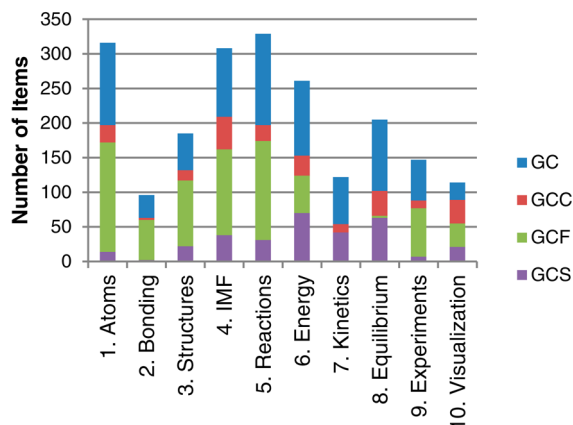


Figure 1. Number of items in each of the 10 level 1 statements (big ideas) on the ACCM across the Full Year General Chemistry (GC), General Chemistry Conceptual (GCC), First Term General Chemistry (GCF), and Second Term General Chemistry (GCS) ACS exams.

distribution of the ACCM statements.⁷ The most commonly tested big idea was Atoms, with 316 items (15.8% of all items) measuring students' understanding of the concept of atoms. In addition, the topics of Intermolecular Forces (IMF) and Reactions were also items that frequently were tested on General Chemistry ACS exams with 308 IMF items (15.4%) and 329 Reaction items (16.5%). The big ideas that were least frequently tested included Kinetics (122 items, 6.1%), Visualization (114 items, 5.7%), and Bonding (96 items, 4.8%).

Looking at the distribution across the 10 big ideas provides initial insights into which overall concepts are assessed on ACS

exams and therefore is helpful for determining what content is being covered in general chemistry courses at a coarse-grained level. Nonetheless, analysis at level 1 does not give depth into which concept details are being assessed or reflect the number of concepts within each of these big ideas. The more detailed look at the enduring understanding statements provides a more nuanced perspective on which concepts were assessed on the General Chemistry ACS exams. Moreover, content that is missing on ACS exams represents holes in the assessment of chemistry concepts and owes to the grassroots development process of these exams, very likely for the course as it is often taught.

In order to determine which content was not tested frequently across the general chemistry database, each of the 1995 items was aligned to the updated version of the ACCM-GC. As a result, each item was assigned to an enduring understanding statement. The distribution of exam items across the different content areas of the map is best visualized by graphing numbers of items in each enduring understanding. Once again, because the ACS exams are developed by teams of instructors who teach general chemistry and validated via trial testing in general chemistry classrooms, an ACCM statement with few items mapped to it most likely represents a concept that is not frequently taught in general chemistry. Therefore, a closer look at the concepts taught within each big idea can give insight into what topics are being taught and assessed in general chemistry. The most accessible presentation of this information is to consider the enduring understandings associated with each anchoring concept separately.

Atoms

Atoms were the most frequently tested big idea. For example, a large number of items were found to be testing "Atoms display a periodicity in their structures and observable phenomena that depend on that structure (1C)" (Figure 2). Another commonly tested enduring understanding statement was "Electrons play the key role for atoms to bond with other atoms (1B)". Of the seven enduring understanding statements that fall under the Atoms big idea, all of them were assessed by at least 20 items. In addition, the majority of items testing atoms are from the first term exams, an observation that is consistent with the customary timing of atoms as an early course topic.

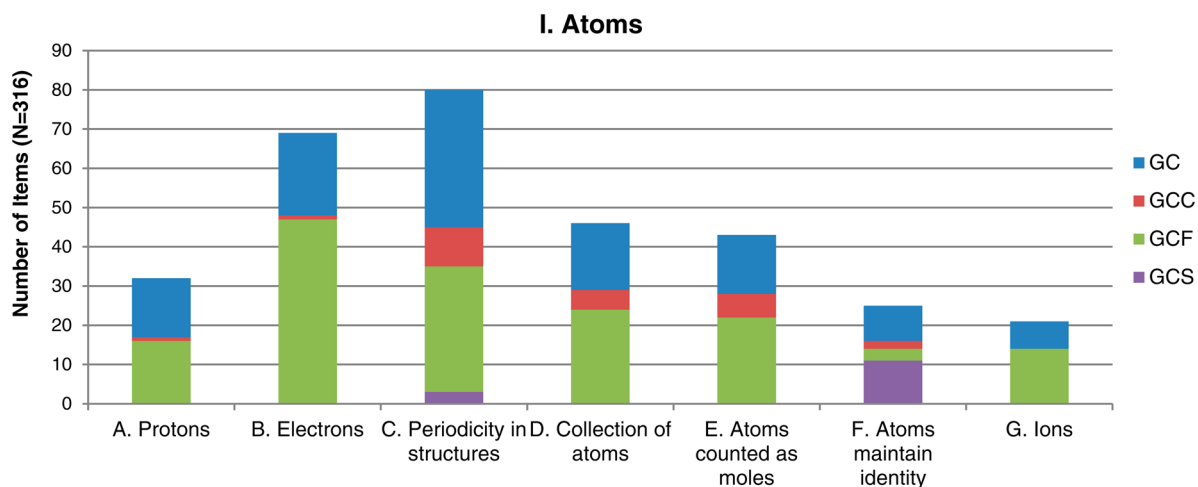


Figure 2. Distribution of items from the Full Year General Chemistry (GC), the General Chemistry Conceptual (GCC), the First Term General Chemistry (GCF), and the Second Term General Chemistry (GCS) ACS exams across enduring understanding statements from the General Chemistry ACCM for big idea 1: Atoms (Note: one GC item overlaps between 1A and 1G).

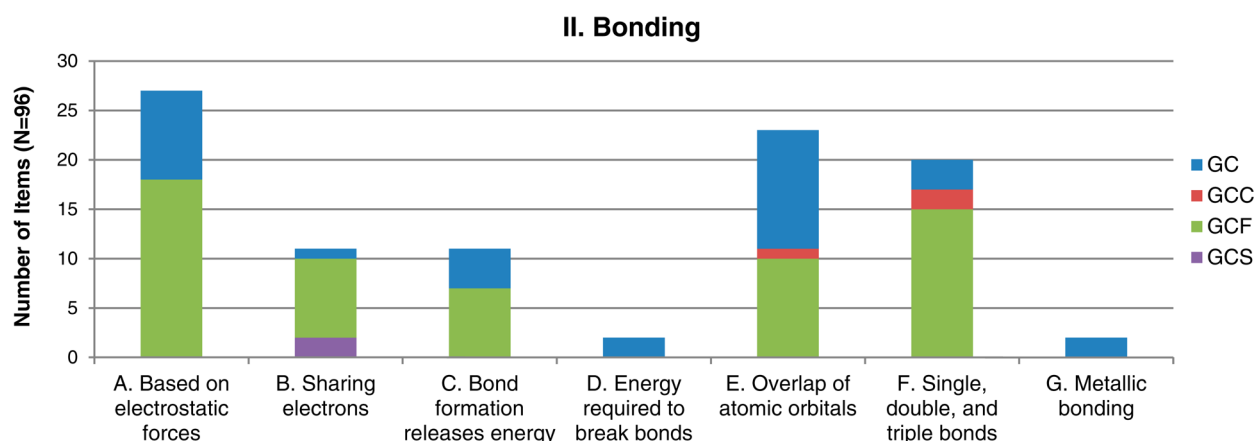


Figure 3. Distribution of items from four types of General Chemistry ACS exams across enduring understanding statements from the General Chemistry ACCM for big idea 2: Bonding.

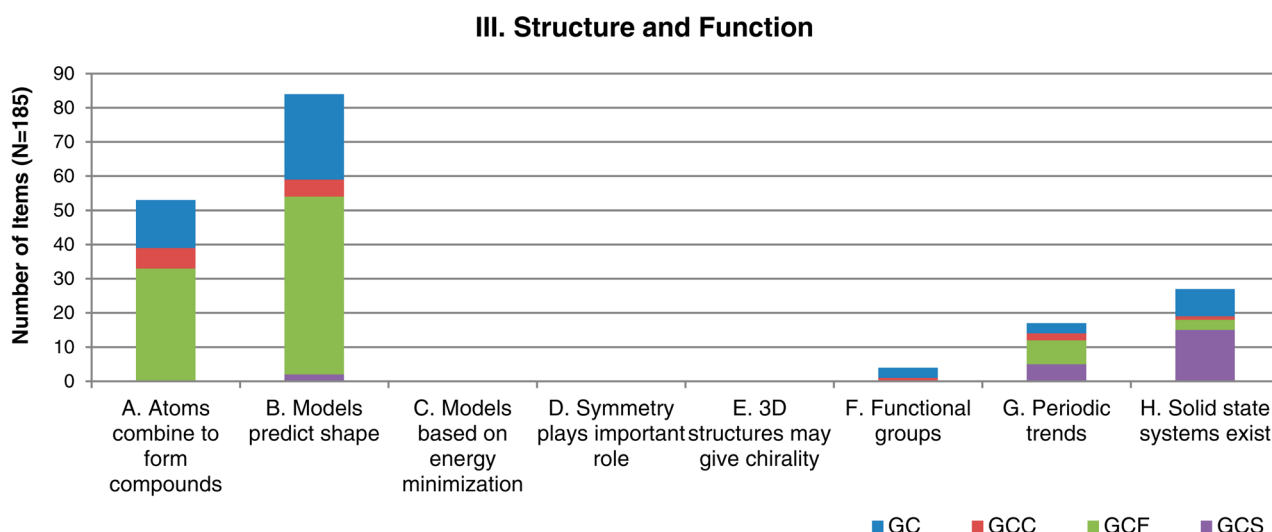


Figure 4. Distribution of items from four types of General Chemistry ACS exams across enduring understanding statements from the General Chemistry ACCM for big idea 3: Structure and Function.

Bonding

Bonding was one of the least tested topics. The concept of breaking a bond requiring an input of energy (2D) was only tested two times across 20 years and four different exam types (Figure 3). This topic is often confused by students when they start learning about the role of ATP in biological mechanisms.¹² This confusion often results in students believing that energy is released when bonds are broken.^{12–15} Metallic bonding (2G) also was only tested twice. A number of researchers have explored students' conceptions of metallic bonding and have shown that students struggle to develop an understanding of how metal atoms bond to one another.^{16–18} While none of the topics were assessed as often as the concepts in Atoms, the most frequently tested enduring understanding statement "Because protons and electrons are charged, physical models of bonding are based on electrostatic forces (2A)" was tested 27 times with roughly one item per individual exam.

Structure and Function

The most common type of questions that were aligned to the Structure and Function anchoring concept asked students to predict shape (3B) with 84 items (Figure 4). This type of question is nearly always testing student understanding of the

VSEPR model for shape and was the second most common question asked on the GCF exams with 7.3% of all items from the first term exams testing shape. Within this big idea, there are three enduring understanding statements that were not tested on any of the exams. These statements serve as examples of cases where the ACCM is designed for usage across the whole undergraduate curriculum, so it is unsurprising that some enduring understandings that are important in later courses are not covered in general chemistry. For example, the enduring understanding statement, "Theoretical models are capable of providing detail structure for whole molecules based on energy minimization methods (3C)", is a concept that would be explored in a physical chemistry course. The second statement, "Symmetry, based on geometry, plays an important role in how atoms interact within molecules and how molecules are observed in many experiments (3D)", often is covered in organic and inorganic courses. And the statement "Three-dimensional structures may give rise to chirality, which can play an important role in observed chemical and physical properties (3E)" is also covered in organic courses. Perhaps more surprisingly, student understanding of functional groups was seldom tested in general chemistry. Across the 1995 items aligned in this analysis, only one item from a conceptual exam

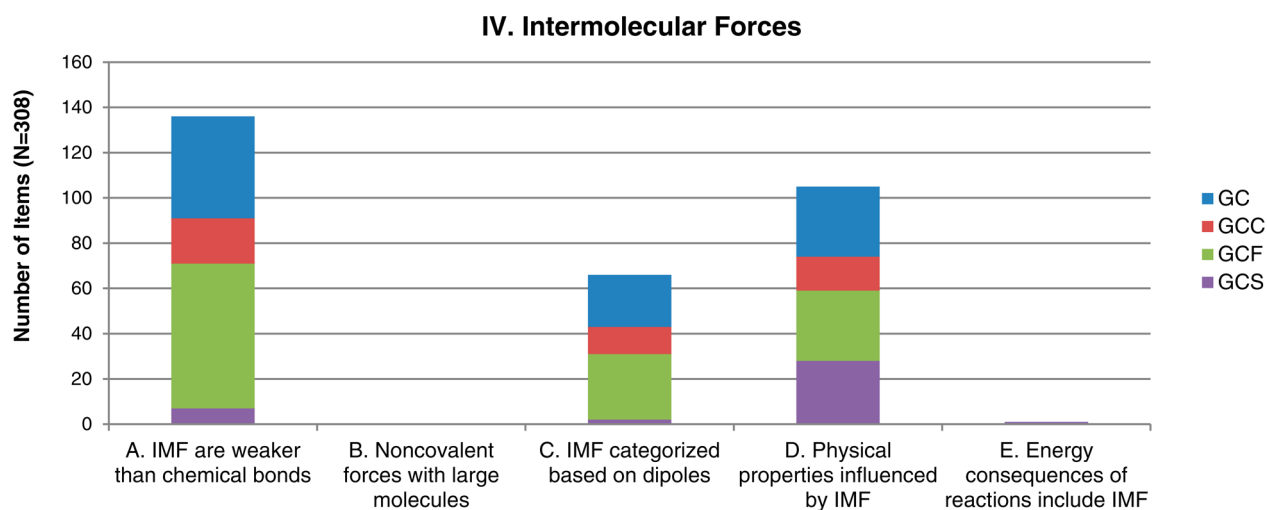


Figure 5. Distribution of items across enduring understanding statements from the General Chemistry ACCM for big idea 4: Intermolecular Forces (IMF).

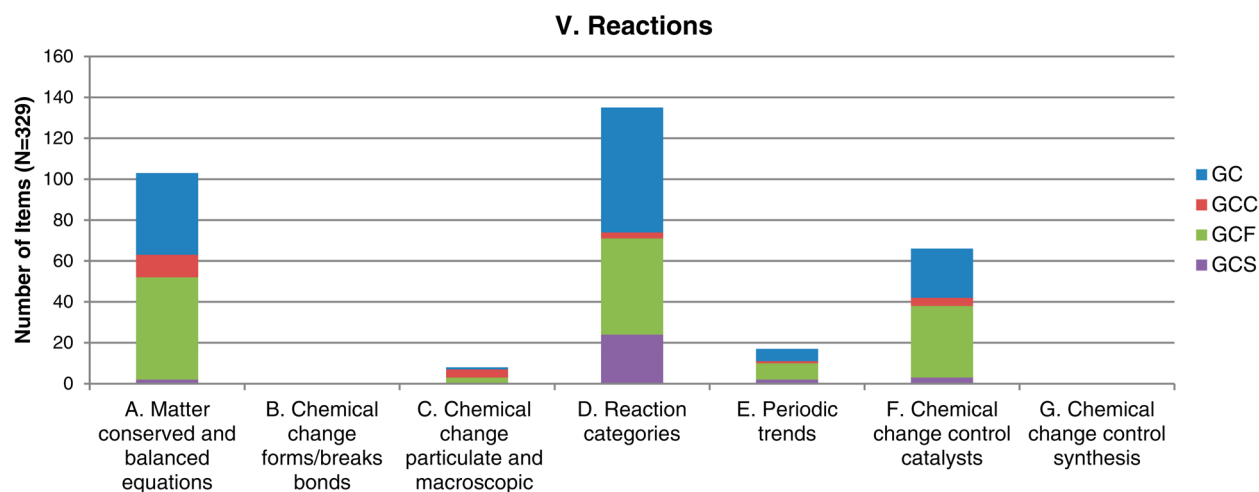


Figure 6. Distribution of items across enduring understanding statements from the General Chemistry ACCM for big idea 5: Reactions.

and three items from full-year exams asked students about functional groups.

Intermolecular Forces

The statement “Intermolecular forces are generally weaker, on an individual basis, than chemical bonds, but the presence of many such interactions may lead to overall strong interactions (4A)” is one of the most frequently asked enduring understanding statements on the map with 10% of all GCC items, 9% of all GCF items, 5.7% of full year GC, and 2.4% of GCS testing this concept (Figure 5). Despite this large assessment effort related to IMF, mapping the items also showed that there were no questions that explored the intermolecular forces that occur within large molecules (4B) on ACS exams in the past 20 years. This apparent hole in content coverage in general chemistry would seem to have implications for the student clientele from other majors. For example, in biology, it is important to realize the importance of hydrogen bonding in several biological processes or structures. Another concept rarely assessed on ACS exams is the idea that “The energy consequences of chemical reactions that take place in condensed phases (solution) usually must include intermolecular forces to be correctly/completely explained

(4E).” In the past 20 years, only one item on the GCS exam assessed this concept.

Reactions

As is evident in Figure 1, the Reactions big idea was the most often tested big idea on the ACS Exams in general chemistry over the past 20 years. One possible factor that contributes to this observation is the relative ease of testing some aspects of reactions, such as classification of the type of reaction (5D). With several different categories, it is easy to assess multiple reactions on the same exam. As a result, 7.8% of all GC items and 6.6% of all GCF items tested students’ ability to classify reaction categories (Figure 6). There were also several items that focused on the conservation of matter and balancing chemical equations (5A, 5.1% of GC, 5.5% of GCC, and 7.0% of GCF items). Even within the substantial overall coverage of reactions, however, there were three enduring understanding statements that were rarely tested. Only eight items (one GC item, four GCC items, and three GCF items) out of 1995 explored students understanding of chemical change at both the particulate and macroscopic levels (5C) through the use of models. In addition, no items measured students’ content knowledge for chemical change arising from the forming and breaking bonds (5B) or the enduring understanding statement

VI. Energy and Thermodynamics

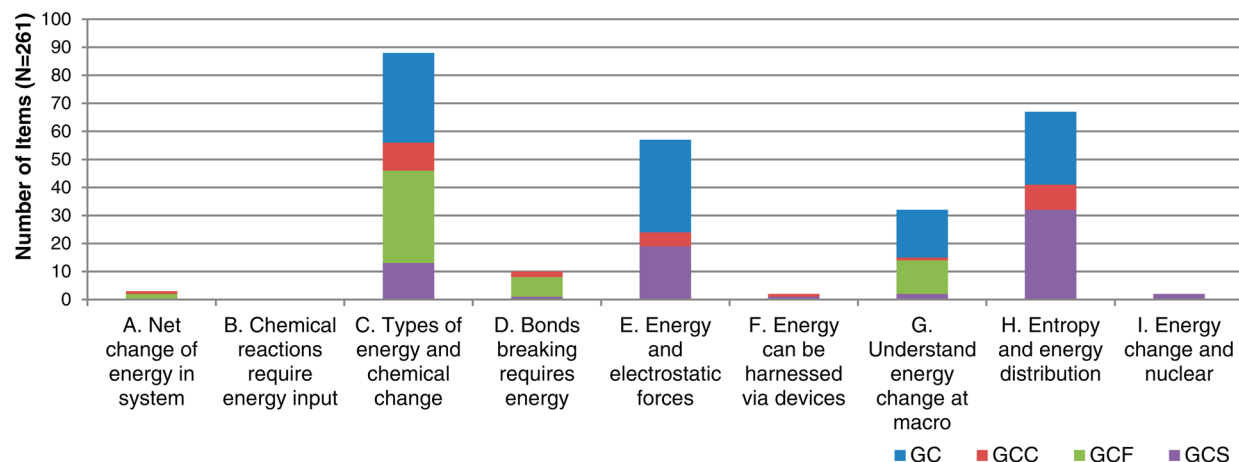


Figure 7. Distribution of items from four types of General Chemistry ACS exams across enduring understanding statements from the General Chemistry ACCM for big idea 6: Energy and Thermodynamics.

VII. Kinetics

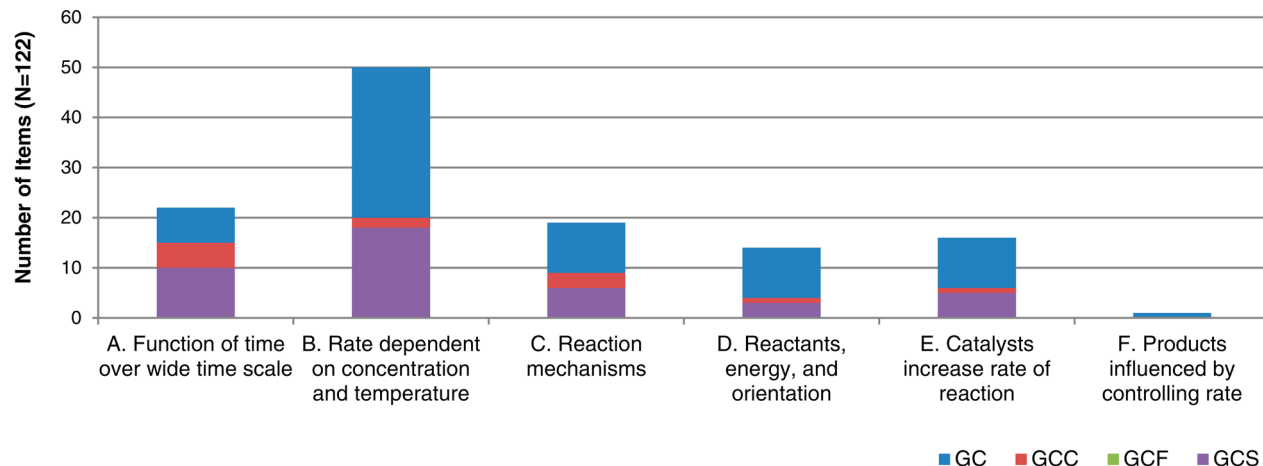


Figure 8. Distribution of items from four types of General Chemistry ACS exams across enduring understanding statements from the General Chemistry ACCM for big idea 7: Kinetics.

relating to how controlling chemical change is useful in synthesis (5G). Once again, this omission emphasizes the broader goals of the ACCM projects, because the role of chemical change in synthesis reactions is a heavily covered topic on organic chemistry exams, so its omission in general chemistry courses is unsurprising.

Energy and Thermodynamics

On ACS General Chemistry exams, the types of energy and chemical change (6C) is the most commonly tested Energy and Thermodynamics enduring understanding (32 items in GC, 10 items in GCC, 33 items in GCF, 13 items in GCS) (Figure 7). However, there are four enduring understanding statements that have been rarely or never tested in the past 20 years. The enduring understanding statement, “Many chemical reactions require an energy input to be initiated (6B)” has not been aligned to ACS General Chemistry exams. It is important to note that some concepts appear in multiple places on the ACCM. While the activation energy was not tested in the context of reactions requiring an energy input, it does appear in the context of kinetics. The concept of net change of energy in the system (6A) has only been measured by three items across

two general chemistry exams (two items on GCF and one item on GCC). The idea that energy can be harnessed via devices (such as a battery, 6F) appeared on one GCC item and one GCS item. Finally, the concept that the magnitude of energy release in nuclear chemistry is much larger than for traditional (atom conserving) chemistry (6I) has only been assessed on two GCS items.

Kinetics

The most commonly asked kinetics question assessed students’ understanding of the rate dependence of concentration and temperature (7B) with 50 items (6.1% of GCS items, 3.8% of GC items, and 1.0% of GCC items) (Figure 8). Only one GC item targeted students content knowledge related to “Reaction products can be influenced by controlling whether reaction rate or reaction energy plays the key role in the mechanism (7F)”. Again, it can be argued that this idea is covered in organic chemistry more frequently than in general chemistry. It is also worth noting for this big idea that kinetics is a topic that normally is covered during the second semester. The second term exam has a slower release rate for ACS exams, so a topic that appears primarily in the second term is predisposed to have

VIII. Equilibrium

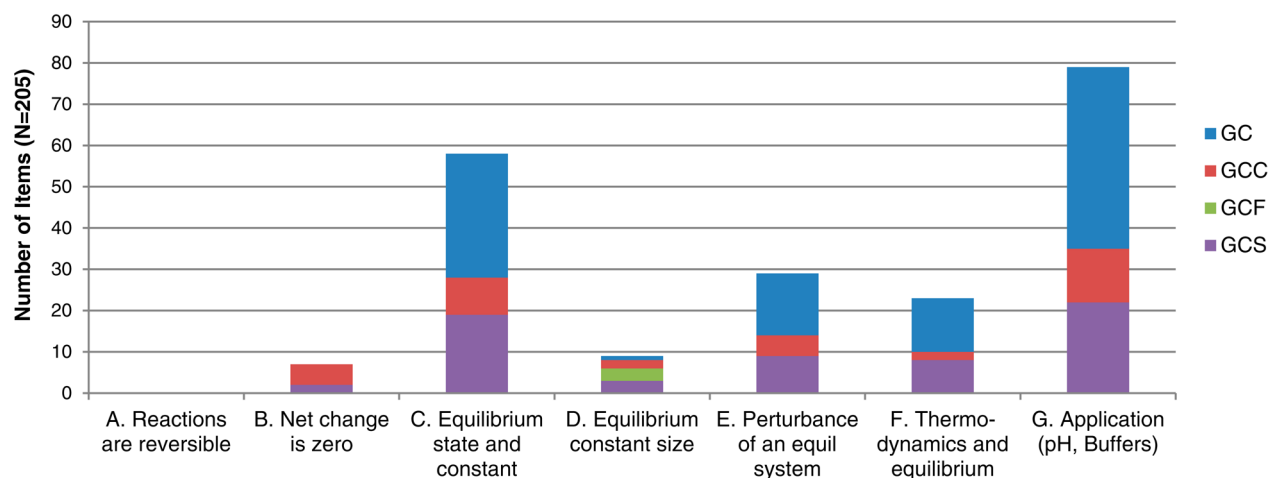


Figure 9. Distribution of items from four types of General Chemistry ACS exams across enduring understanding statements from the General Chemistry ACCM for big idea 8: Equilibrium.

IX. Experiments

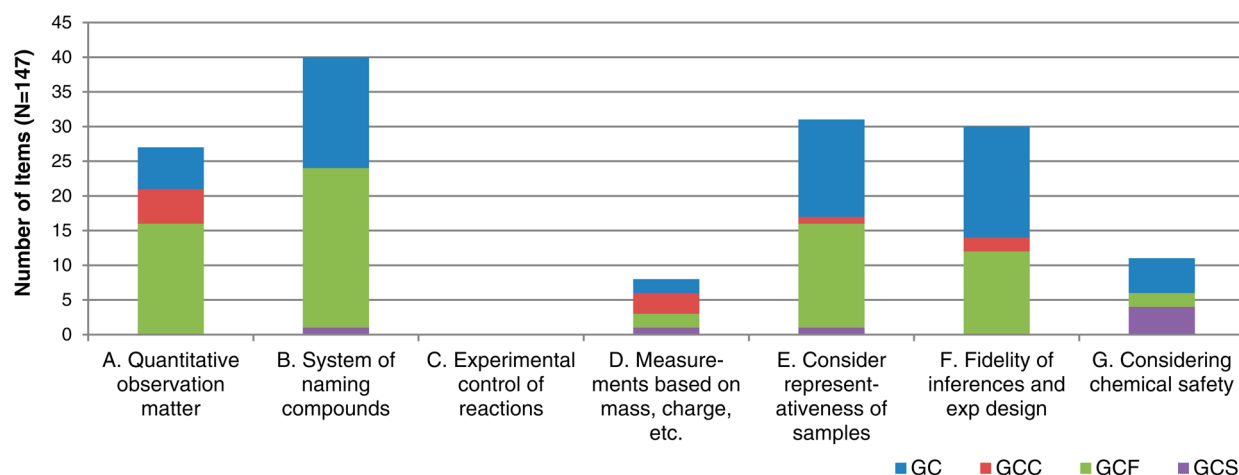


Figure 10. Distribution of items from four types of General Chemistry ACS exams across enduring understanding statements from the General Chemistry ACCM for big idea 9: Experiments.

fewer instances in the sample being studied than a topic that would appear primarily in the more often rewritten first-term exam.

Equilibrium

The big idea Equilibrium is frequently tested on ACS General Chemistry exams. Approximately one-fifth of GCS and GCC items test equilibrium. The most frequently tested enduring understanding statement is “equilibrium concepts have important applications in several subdisciplines of chemistry (8G)” (Figure 9). The questions in this category include those that assess buffers and applications of acid–base chemistry, that is, titrations and pH. Very few questions covered the idea that, at equilibrium, the net change of reactant and product amounts is zero (8B, five GCC and two GCS items). Interestingly, no items explicitly assessed the idea that phase changes are reversible (8A). It may be that items related to phase diagrams incorporate knowledge of this concept, but those items do not explicitly require it. The literature on conceptual understanding of chemistry has many examples of how students can correctly answer one type of item for a topic and yet demonstrate a lack

of conceptual understanding related to that topic.^{19–21} Thus, it may be important to consider whether or not explicit testing of foundational ideas such as this one might merit more attention among test developers.

Experiments

The role of experimental evidence in understanding chemistry has been present in 7.3% of all general chemistry exam questions (147 items). Within the big idea Experiments, seven enduring understanding statements have further explored the type of experimental questions assessed on the ACS General Chemistry exams. The most prevalent enduring understanding is essentially chemical nomenclature, “Because there are a large number of compounds, a system of naming these compounds is used (9B)” with 40 items testing students’ knowledge of how compounds are named (16 items from GC, 23 items from GCF, one item from GCS) (Figure 10). On the other hand, only eight of the 147 items assessed students understanding of “Chemical measurements are based on mass, charge, temperature, pressure, volume, or interaction with electrons or photons (9D)”. In other words, the specifics of what must be

X. Visualization

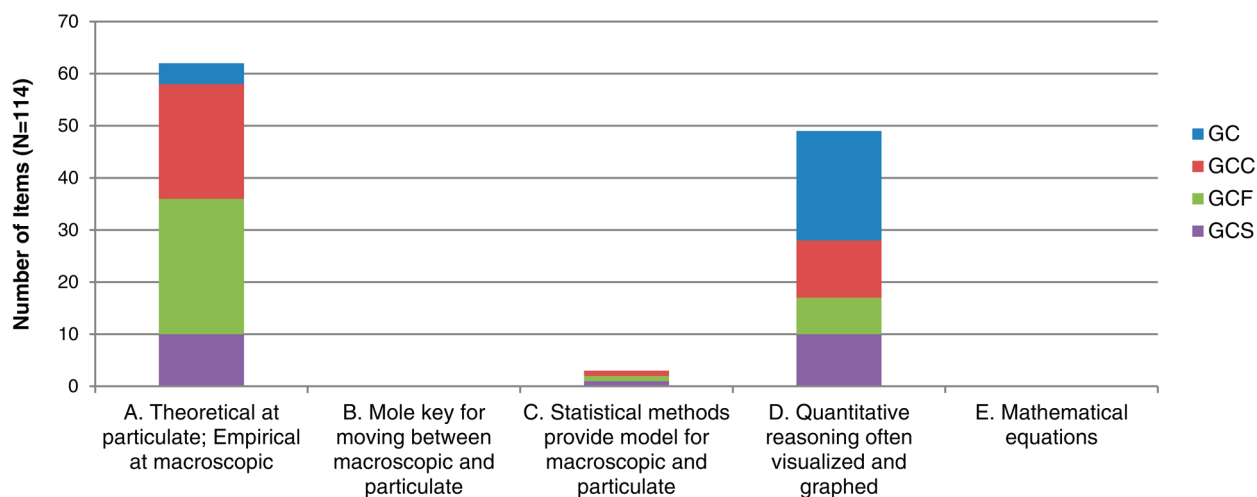


Figure 11. Distribution of items from four types of General Chemistry ACS exams across enduring understanding statements from the General Chemistry ACCM for big idea 10: Visualization.

Table 2. Number of General Chemistry ACCM Items Assigned to Enduring Understanding Statements from the Second Version of the General Chemistry ACCM That Are Rarely Assessed in over 20 Years on Four Different General Chemistry Exams Compared to the Number of Level 3 Statements

Big Idea (Total Number of Level 2 Statements)	Enduring Understanding (Level 2) Statement	Level 3 Statements	Items Assigned to Level 2
Bonding (7)	To break a chemical bond requires an input of energy.	1	2
	Metallic bonding arises in many solids and fundamentally involves the sharing of valence electrons among many positively charged "cores" over extended distances.	2	2
Structure and Function (9)	Theoretical models are capable of providing detail structure for whole molecules based on energy minimization methods.	0	0
	Symmetry, based on geometry, plays an important role in how atoms interact within molecules and how molecules are observed in many experiments.	0	0
	Three-dimensional structures may give rise to chirality, which can play an important role in observed chemical and physical properties.	0	0
Intermolecular Forces (5)	For large molecules, IMFs may occur between different regions of the molecule. In these cases, they are sometimes termed noncovalent forces.	1	0
	The energy consequences of chemical reactions that take place in condensed phases (solution) usually must include IMFs to be correctly/completely explained.	1	1
Reactions (7)	Chemical change involves the breaking or forming of chemical bonds, or typically both.	1	0
	Controlling chemical reactions is a key requirement in the synthesis of new materials.	1	0
Energy (9)	Many chemical reactions require an energy input to be initiated.	1	0
	In accord with thermodynamics, energy is conserved in chemical changes, but the change of form in which the energy is present may be harnessed via natural or human-made devices.	2	2
Kinetics (6)	Reaction products can be influenced by controlling whether reaction rate or reaction energy plays the key role in the mechanism.	1	1
Equilibrium (7)	Both physical and chemical changes may occur in either direction (e.g., from reactants to products or products to reactant).	1	0
Experiments (8)	Experimental control of reactions plays a key role in the synthesis of new materials and analysis of composition.	1	0
Visualization (5)	The mole represents the key factor for translating between the macroscopic and particulate levels.	1	0
	Macroscopic properties result from large numbers of particles, so statistical methods provide a useful model for understanding the connections between these levels.	2	3
	Mathematical equations provide a tool to visualize chemical and physical processes.	1	0

measured to make inferences from laboratory data is not often assessed on ACS exams. None of the items on the four types of the aligned General Chemistry ACS exams assessed knowledge of the idea that "Experimental control of reactions plays a key role in the synthesis of new materials and analysis of composition (9C)". Once again, this topic plays a much more important role in a subsequent ACCM, in this case the map currently under development for the analytical chemistry course.

Visualization

This anchoring concept is the second-least-populated big idea within the ACCM-GC. Moreover, the majority of the items that were classified as visualization items were also aligned to another portion of the map. Within the alignment process, there was no constraint that items must fit into a single location on the map, though when possible this style of alignment was the goal of the raters. A key component of the visualization anchoring concept lies in the conceptual understanding of the

particulate nature of matter, and this idea is often used in a complementary way with topics such as reactions or bonding. The most common visualization enduring understanding statement for the General Chemistry ACS exams was “Many theoretical constructs are constructed at the particulate level, while many empirical observations are made at the macroscopic level.” Four GC items, 22 GCC items, 26 GCF items, and 10 GCS items were placed on this portion of the map (Figure 11). These items in particular tend to focus on particulate level diagrams (i.e., mixture vs pure substances). There were two Visualization enduring understanding statements that were not represented on the General Chemistry ACS exams. The first enduring understanding statement not represented was, “The mole represents the key factor for translating between the macroscopic and particulate levels.” While there are items that ask students to mathematically convert between grams and number of atoms, these items did not require students to hold an understanding in terms of being able to visualize the connections between the macroscopic and particulate levels. These items instead were coded to 1E and 5A, which both included stoichiometry conversions in the context of Atoms and Reactions, respectively. It was not surprising that this topic was not assessed on the general chemistry exams. It is difficult to access in a multiple choice item students understanding of mole ratios by connecting particulate level and macroscopic level understanding. The second visualization enduring understanding statement that was not represented was “Mathematical equations provide a tool to visualize chemical and physical processes.” This concept of using mathematical tools for analysis is more commonly part of advanced courses in physical or inorganic chemistry. General chemistry exams tend to have equations as a tool to obtain quantitative information rather than one that provides analysis of topics.

CONCLUSION

Because chemistry, as a discipline, has invested significant time and effort to maintain a program of norm-referenced exams, the items that appear on those exams provide an artifact of the content coverage of this course. To assess this coverage, a large-scale alignment project of roughly 2000 items from ACS General Chemistry has been completed. Importantly, there are several areas of the General Chemistry ACCM that have not been assessed through the use of ACS General Chemistry exams (GC, GCC, GCF, GCS). In a previous publication, an overall look at the distribution of items into the Anchoring Concept Statements revealed that ACS exams tend to favor asking questions about atoms, intermolecular forces, and reactions.⁴ Because of the manner in which ACS Exams are developed,² this observation tends to suggest that these topics are frequently incorporated into the general chemistry course.

Ultimately, there are 17 enduring understanding statements on the General Chemistry ACCM that are not currently represented or are sparsely represented though the ACS exam items over the past 20 years as summarized in Table 2. While some enduring understanding statements are not anticipated to be covered in general chemistry, there are a few areas that seem fairly important in terms of chemistry that students majoring in other sciences need.

It is important to consider possible reasons why the observed holes in the content coverage of ACS General Chemistry exams may occur. Some of these reasons are associated with the exam development process itself. Exam committees are composed from instructors who teach the course, and as a result, these

groups generally reflect the expertise of the majority of instructors. For general chemistry, this leads to development committees that tend to have instructors who have formal training predominantly in either inorganic chemistry or physical chemistry. There are, therefore, relatively few experts that might initially compose questions with more biochemistry content, for example, because such instructors are seldom part of the committee. Perhaps more importantly is the fact that ACS exams include a trial testing phase, where item performance is gauged with students in the course for which the exam is intended. Committees often do try to construct items that address other areas of chemistry, but if that content fares quite poorly during trial testing, it may not be included on the final version of the exam.

Even with these caveats about the exam development process, there are worrisome trends revealed by the analysis presented here. It may be understandable, for example, that small molecules are often used for items about intermolecular forces. Small molecules are useful in terms of addressing fundamental aspects of this topic. Nonetheless, the complete lack of items that include intermolecular forces related to large molecules likely constitutes an important omission that arguably requires specific efforts to address. As noted earlier, a majority of the students in general chemistry are pursuing degrees related to life sciences, and these students ought be required to extend their knowledge of intermolecular forces. Allowing this topic to be left to other courses in biology or biochemistry rather than general chemistry loses the opportunity for “near transfer”.^{2,3} In other words, students are more likely to develop a deeper and more encompassing view of noncovalent forces when those connections begin to be made as the concept is developed than they are if they do not see noncovalent interactions again until much later, perhaps in another course that lacks the time to cover the connection to intermolecular forces in small molecules.

Similar arguments might be made for other low-coverage content, such as metallic bonding, with other constituents, such as pre-engineering students. Curricular reform efforts face a challenging zero-sum game, so it is not immediately obvious which of the low-coverage content in Table 2 should be aggressively added to the general chemistry curriculum and which content holes might be acceptable. Nonetheless, as the example of noncovalent forces in large molecules shows, there are content areas that if developed more fully would certainly provide important concepts for a sizable fraction of the students in the course. Evidence such as that revealed by the analysis presented here will hopefully provide guidance to those who are interested in enhancing the relevance of chemistry courses to the students who are taking them. By looking at the content coverage of ACS exams, this study suggests some places, such as noncovalent forces in large molecules, where content bridges to other disciplines might be most strongly needed.

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

Partial funding for the development of the ACCM was provided by the National Science Foundation (NSF-DUE

071779, 0943783). Alignment work and continued refinements to the ACCM carried out under the auspices of NSF-DUE 1323288. Any opinions, findings, and conclusions communicated in this material are those of the authors and do not necessarily reflect the views of the NSF.

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