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Abstract

The ACS Examinations Institute has been developing Anchoring Concepts Content Maps to provide an organizational template for the four-year undergraduate chemistry curriculum. In order to accomplish this goal, specific subdisciplinary versions of the map share the two top levels but distinguish themselves at the bottom two levels which contain finer-grained content details. This structure has been refined and vetted over a number of meetings and workshops. This paper presents the four levels of the content map for physical chemistry.

Keywords

Upper-Division Undergraduate, Physical Chemistry, Testing/Assessment, Curriculum

Disciplines

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Comments

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The ACS Exams Institute Undergraduate Chemistry Anchoring Concepts Content Map IV: Physical Chemistry

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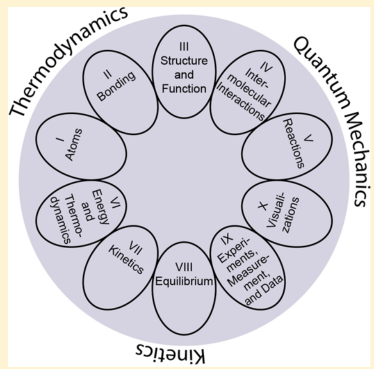
S *Supporting Information*

ABSTRACT: The ACS Examinations Institute has been developing Anchoring Concepts Content Maps to provide an organizational template for the four-year undergraduate chemistry curriculum. In order to accomplish this goal, specific subdisciplinary versions of the map share the two top levels but distinguish themselves at the bottom two levels which contain finer-grained content details. This structure has been refined and vetted over a number of meetings and workshops. This paper presents the four levels of the content map for physical chemistry.



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■ INTRODUCTION

An interesting challenge associated with broad-based curriculum change efforts in undergraduate chemistry programs lies in the historical division of the content into the traditional subdiscipline areas of the field. For many years, the metrics for program approval by the American Chemical Society (ACS) largely enshrined this approach by counting courses taken as defined by the subdisciplines. More recently, guidelines from the ACS Committee on Professional Training (CPT)[1] have shifted toward assessment of student learning as the metric for approval, allowing for more flexibility in curricula, at least in principle. Importantly, the need for assessment tools becomes particularly noteworthy when content coverage changes are a key component of innovation in undergraduate teaching. In at least one important way, chemistry education is well placed to move toward enhanced assessment approaches for organizing curricular change evaluation, because the ACS Examinations Institute (ACS-EI) has provided nationally normed exams in the various chemistry subdisciplines for many years. As a result, there are externally validated assessment tools available to provide evidence related to longitudinal efforts a department might undertake to reform the undergraduate chemistry curriculum. To better serve this type of use of ACS Exams, the ACS-EI has been working for several years with chemistry instructors to construct Anchoring Concepts Content Maps (ACCM) to provide a template with common features in addition to subdiscipline specific components that are either currently in development or have been published.[2−6]

This article presents the development of the ACCM for physical chemistry, along with the PChem-ACCM itself as Supporting Information. The approach taken over the years to develop the ACCM has been described elsewhere,[2,3] and previously published content maps exist for general chemistry,[4,5] organic chemistry,[6] and inorganic chemistry.[7] The top level of organization of the 4-level ACCM consists of 10 anchoring concepts that can be thought of as "big ideas" that arise to some extent at every stage of the chemistry curriculum. Starting from these anchoring concepts, a four-level hierarchical structure is constructed with each subsequent level providing finer-grained statements of chemistry content. Statements at the second level of the map are designed to articulate slightly finer-grained, core concepts that serve as foundations for long-term learning in all of the subdisciplines. Borrowing terminology from evidence-centered design,[8,9] these statements are referred to as "enduring understandings". All subdisciplinary versions of the ACCM are built from the same set of level 1 and 2 statements. While the top two levels provide the important commonalities of chemistry content across the 4-year curriculum, level 3 statements emphasize content coverage most pertinent to coursework in each subdiscipline. This level is referred to as the "subdisciplinary articulation" and represents the key point at which each map provides content specifications that are unique. The subdisciplinary articulations are still

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Table 1. Summary of Activities for the Construction of the Physical Chemistry ACCM

Meeting or Conference	Date	Focus Group Activities
ACS National Meeting	April 2008	Level 1 and 2 synthesis
ACS National Meeting	March 2010	Level 3 brainstorming
ACS National Meeting	March 2011	Level 3 testing and refinement
ACS National Meeting	August 2012	Level 3 testing and refinement and level 4 brainstorming
ACS National Meeting	August 2014	Additional level 4 brainstorming, initial alignment of physical chemistry exam items
Biennial Conference on Chemical Education	August 2016	Refinement of level 3 and 4 statements, alignment of physical chemistry items from "Comprehensive" exam
Exams Institute Office (staff)	Fall 2016−Winter 2017	Review and editing of levels 3 and 4
ACS National Meeting	April 2017	Additional level 4 refinement, additional alignment of physical chemistry comprehensive exam items
ACS Regional Meeting	June 2017	Additional level 4 refinement, alignment of physical chemistry comprehensive exam items

designed to be somewhat more coarse-grained, so they are further divided into "content details" at level 4 of the ACCM. Teams of volunteers who are instructors in each of the various subdisciplines of chemistry have contributed to the development of levels 1 and 2 of the ACCM while establishing level 3 and 4 statements of the map within their own subdiscipline.

■ PHILOSOPHY OF THE ACCM

While there are several possible uses for the ACCM, the ACS-EI has sought to create this tool in conjunction with its history of developing summative exams for use in all levels of chemistry courses. For a given course, an ACS Exam is developed by a group of instructors from around the US who teach that course.[10] This type of work by instructors served as the backbone of the development for the various ACCMs as well. One key difference, however, is that the efforts of volunteers were not associated with appointed committees, but rather associated with workshops held at regional and national ACS meetings. In developing the ACCM for a topic like physical chemistry that is often divided into separate courses, workshop participants intentionally attempted to be highly inclusive of content, so that individual differences in emphasis would not lead to instructors perceiving that their coverage choices were missing from the map. As such, the physical chemistry map is like each of the other maps in the various subdisciplines as it contains more content than is covered within a single course.

In part because of this desire for a relatively exhaustive list of content, the ACCM presented here is also not intended to establish a preferred coverage of physical chemistry topics. Rather, from the perspective of the ACS-EI, the ACCM is designed to provide a structure that spans the content coverage of the four-year chemistry curriculum and can be used as a tool for the alignment of exam items. The ACCM is not limited to use with testing, and instructors can find other ways to leverage its organization, such as aligning learning objectives in courses. Nonetheless, for the purpose of an assessment organization such as ACS-EI, the alignment of exam items remains the primary benefit to establishing the ACCM. An example of how this type of work can lead to important observations has been the identification of trends in content coverage of ACS Exams in courses designed for the first two years of the curriculum.[11−15] These types of alignment studies are not unique, and Cooper and co-workers have suggested alternative processes for enhancing the role of content assessment in the first two years of the curriculum.[16]

While there has been significant effort associated with the physical chemistry ACCM to reach a point where the map represents a broad overview of the physical chemistry curriculum and assessment topics, thus meriting publication, it is important to recognize that the content coverage choices of physical chemistry are not set in stone. As such, future revisions of the ACCM are likely. One source of revisions is that as content maps in other subdisciplines are completed, some changes in levels 1 and 2 occasionally occur. When this happens, all the maps that have already been established need to "back fit" the new structure, which may also include additional revisions to the level 3 and 4 statements. This dynamic approach has already been used for the first ACCM published in general chemistry, for which an update to the original ACCM has been published.[6]

■ DEVELOPMENT OF THE PHYSICAL CHEMISTRY ACCM

As noted earlier, the level 1 and 2 statements of the ACCM are common to all of the maps and were largely developed independently of the physical chemistry map.[3−5] Nonetheless, even the level 3 and 4 statement creation in physical chemistry presents challenges associated with the traditional organization of the content in this subdiscipline. As noted in the graphical abstract, for several decades now, the content of physical chemistry has three overarching areas, kinetics, quantum mechanics, and thermodynamics. By framing these traditional areas within the lens of the 10 level 1 "big ideas" of the content map, additional content themes begin to emerge.

Over the past 40 years, several volumes[17−19] have been published by the American Chemical Society with discussions about the undergraduate physical chemistry curriculum. A majority of the contributed chapters in these books have tended to focus on relatively fine-grained components of the curriculum more than discussing the content domain in broader terms. There have been discussions about issues related to order of teaching the content areas of physical chemistry,[20] which include the role of statistical mechanics and how early it should be taught.[21] Teaching physical chemistry with a blended approach using both quantum and statistical mechanics as the basis for thermodynamics has also been presented.[22] Many of these arguments have been put into the context of chemistry education research by Mack and Towns,[23] which included an investigation of learning goals of physical chemistry faculty at a number of US universities. It is important to note that the overall structure of the ACCM, with consistent statements for levels 1 and 2 across the curriculum, results in the information presented here framing this discussion in a quite different way.

The anchoring concepts provide a new perspective in which the main content areas of thermodynamics, quantum chemistry,

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and kinetics contribute in various ways. For example, even though there are anchoring concepts that highlight both kinetics (anchoring concept 7) and thermodynamics (anchoring concept 6), there are additional places within the physical chemistry ACCM where statements related to these ideas may be found. One example, of many, is that thermodynamic concepts related to phase changes are part of the understanding forged in physical chemistry courses about the role of intermolecular forces in chemical systems within anchoring concept 4.

One challenging aspect of mapping the content of physical chemistry with an eye toward assessment lies in the mathematical concepts that are part of the course. These mathematical aspects are critical to the development of models in all areas of physical chemistry and as such may merit test items to assess student understanding. From the perspective of the ACS-EI, an individual test item related to this type of mathematics may test the mathematical reasoning and not specifically apply that reasoning to a physical system. This type of assessment is commonly related to interpretations of graphical information, and as a result the idea of representing chemical and physical systems with mathematical models can often be found within anchoring concept 10, which is centered on visualizing and using representations.

With consideration of the logistics side of the creation of the physical chemistry ACCM, Table 1 provides the timeline of the workshops where participants worked on different aspects of the map.

ACS Exams produces a number of different exams for physical chemistry, including a Thermodynamics exam,[24] a Quantum exam,[25] and a Comprehensive exam[26] with 20 items for each of thermodynamics, quantum, and kinetics/dynamics, and a modular exam,[27] which is designed to allow instructors to mix and match components that reflect what gets taught (typically) in the two different semesters of the course. Alignment efforts used during the development of the ACCM for physical chemistry used the comprehensive exam in order to provide test items that spanned all three of the primary areas of the content domain. A more detailed description of the alignment process used by workshop participants and ACS-EI staff to align ACS Exam items to the ACCM can be found elsewhere,[3,11] but in general the process involves looking at an individual item, identifying the content "big idea" (level 1) where the item fits, and then selecting statements in the subsequent levels that best represent the item's content. At the end of the alignment process, the goal is for each exam item to have a four-coordinate "address" representing where the item's content resides within each of the four hierarchical levels on the ACCM. During the content map development process, items that did not readily align to a location on the map provided insight into areas of the map where content expansion was necessary. In addition to the workshops, a few volunteers looked at the emerging map individually along the way, and their comments were incorporated by ACS Exams staff members in refining statements that appear, particularly at level 4.

SUMMARY

In conclusion, the Physical Chemistry Anchoring Concepts Content Map is presented, and is available in outline form in the Supporting Information for this article. As noted, there are some specific challenges for the development of this version of the ACCM, but the general process used for development of these maps has been reported previously.[3,4] Alignment of ACS Exams items to this map is an ongoing process that, once completed, will help instructors who use these exams identify content coverage within this anchoring concept template, which is designed to assist departments and instructors with considering their content coverage over the course of a four-year curriculum. Nonetheless, like the previously published versions of the ACCM,[4−7] instructors may find additional uses for the content domain information contained in this map, beyond assessment. Finally, as has been evident from the earlier efforts, this map is being presented after significant input from physical chemistry instructors, but continued feedback and comments may lead to revisions. Each of the ACCM is ultimately expected to be continuously refined, and the physical chemistry map is no exception to this expectation.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00531.

ACS-EI Anchoring Concepts Content Map as articulated for physical chemistry (PDF)

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Notes

The authors declare no competing financial interest.

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