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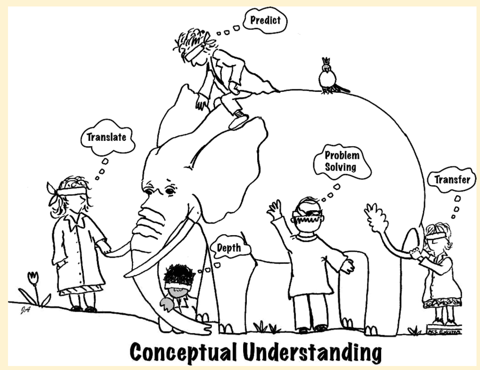
Defining Conceptual Understanding in General Chemistry

Thomas A. Holme,* Cynthia J. Luxford, and Alexandra Brandriet

Department of Chemistry, Iowa State University, Ames, Iowa 50011, United States

ABSTRACT: Among the many possible goals that instructors have for students in general chemistry, the idea that they will better understand the conceptual underpinnings of the science is certainly important. Nonetheless, identifying with clarity what exemplifies student success at achieving this goal is hindered by the challenge of clearly articulating what conceptual understanding entails. While this may be a case of "we know it when we see it", the design of assessments ultimately requires a specific definition of conceptual understanding. Without such a specific definition of the construct, it may be readily argued that a proposed measure does not provide evidence about, in this case, conceptual understanding because the construct itself is insufficiently identified. Given the wide range of possible definitions, the availability of empirical data about instructor perceptions of the meaning of conceptual understanding can play an important role in constructing a definition that meets the broadest possible needs of the chemistry education community. Thus, with the aid of roughly 1,400 instructor written definitions, a consensus articulation of conceptual understanding is identified in this work.



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

■ INTRODUCTION

Instructors of general chemistry courses have a range of goals for their students to achieve, and these goals are sometimes vaguely defined. Content knowledge is invariably the primary goal, but even then specifics about what type of content, both in terms of topics and the standard for understanding topics, may vary. One particular aspect of student understanding in general chemistry that has attracted attention over the past several years is the distinction between conceptual understanding and the capacity to carry out algorithmic calculations.

Investigations into the distinctions between algorithmic and conceptual learning in chemistry were first reported in the late 1980s with a series of studies by Pickering and colleagues[1,2] and investigations about student understanding of the particulate nature of matter (PNOM) by Gabel et al.[3] In the early 1990s, Nakhleh and co-workers expanded this work with a series of studies that focused on the differences between concept learning and algorithmic problem solving.[4−6] In their review of the problem solving literature, Gabel and Bunce suggested that one of the main reasons that students struggle to solve problems is that they lack the understanding of necessary chemical concepts.[7] These and other important studies[8−17] have further established the evidence that students are often capable of using algorithms to solve numerical problems but may not be able to answer non-numerical questions about essentially the same content. These observations established a long-standing hypothesis that the conceptual underpinning of chemistry is not necessarily as well formed for many students as their numerical problem solving.

Taken as a whole, these pioneering studies and many additional efforts in the years since have delineated an idea that "conceptual understanding" is a distinguishable construct.[1−17] Nonetheless, the definition for conceptual understanding in chemistry has arguably been inferred rather than specified in detail. It is most often viewed relative to some standard (algorithmic problem solving) that it is not.[1,2,4−6]

At the same time, most chemistry instructors have an intuitive feel for what is meant by conceptual understanding. Unfortunately, intuition is an inherently personal trait, so there is no particular reason to expect that any given pair of chemistry instructors will have the same intuitive definition of conceptual understanding. The study reported here, which considers definitions from roughly 1,400 chemistry instructors, demonstrates the variability of these intuitive understandings of student conceptualizations of general chemistry. In this sense, the collective intuition of the chemistry education community resembles the story of blindfolded observers interacting with different parts of an elephant.[18] In the classic parable/poem, different locations being encountered result in different objects being described, and yet all of the observations are describing only a part of the whole. The primary benefit of articulating the various ways that chemistry instructors view conceptual understanding is to bring into focus the greater whole of the definition.

This situation does not imply that no efforts have been made to articulate specific aspects of conceptual understanding. In science generally, Roth[19] discussed several different components of meaningful conceptual understanding as needing to go beyond knowing facts and the novelty of the situation driving the meaningfulness of conceptual knowledge. In addition, Roth also used different perspectives to emphasize the need for students to be able to make predictions and build explanations.

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In ecology, Puk and Stibbards[20] have identified at least one aspect of their definition to be "The ability to see these interconnections between concepts reflects what we call 'conceptual understanding'...". Finally, in math, Rittle-Johnson, Siegler, and Alibali[21] defined conceptual knowledge as "Implicit or explicit understanding of the principles that govern a domain and of the interrelations between units of knowledge in a domain." They also stated that conceptual understanding is both flexible and generalizable as well as highlight assessment of conceptual understanding as asking participants in a research setting to count or solve a problem in nontraditional ways.

The ACS Examinations Institute (ACS-EI) has produced exams designed to test conceptual understanding. The first Conceptual Exam committee developed conceptual questions that focused on using pictorial PNOM images or linking predictions to explanations using both traditional general chemistry topics as well as laboratory topics.[22] In addition, the ACS-IE has also developed Paired Item exams for both first and second semester general chemistry, where students are given both traditional (algorithmic) questions and conceptual questions that measure the same content.[23] In addition to ACS exams, concept inventories are also available to assess students' conceptual understandings as well as the misconceptions students hold across a variety of topics, such as bonding,[24] redox,[25] and thermodynamics.[26] Despite the growing body of literature on students' conceptual understandings, there has been a modest, or nonexistent, discussion of what conceptual understanding is and how it can be measured.

The lack of a specific articulation of the definition of conceptual understanding presents an important problem for testing student learning in general chemistry. If the community of chemistry instructors have differing definitions of what conceptual understanding means, it is not clear that such tests would uniformly accomplish their stated goal of measuring that understanding. As a result of this ambiguity, the test development process[27] for the newest Conceptual General Chemistry exam from ACS-EI included survey research to establish a snapshot of what chemistry instructors perceive conceptual understanding to be. In addition to querying instructor views about specific examples of putative conceptual test questions, an opportunity to provide an open response definition of conceptual understanding was included. Responses to this task can be used to form the basis of a specifically articulated definition of conceptual understanding capable of reflecting the variety of intuition about this idea held among chemistry educators. The analysis of these definitions is presented here, and a consensus definition is proposed that incorporates a large majority of the survey responses.

■ SURVEY DESIGN

As part of the market research conducted at the ACS-EI, a need-based assessment of exams testing conceptual understanding was conducted in August of 2013. The survey consisted of three main parts. The first set of questions explored the backgrounds of the participants through a series of demographic questions. The second set of questions focused on conceptual understanding through topics taught and question structure. At the end of the section, participants were asked to generate their own working definition of conceptual understanding. The last section of the survey focused on scientific practices used in their classrooms. Survey questions in sections one and two were created by the 2015 General Chemistry Conceptual Exam Committee, whereas questions in section three were developed from separate interview data generated by ACS-EI about faculty evaluation of science practices in their classrooms.[28] Survey items were pilot tested with members of the exam development committee to determine face validity and content validity. Feedback from the pilot test was used to refine the items before being sent out as a national survey. There were many findings from this survey; the work presented here arises from instructors responses to the question: "In your own words, what is conceptual understanding?" The data from this question was analyzed to answer the questions: (1) How do faculty members who teach general chemistry define conceptual understanding? (2) What common threads are frequently used in general chemistry faculty members' definitions?

■ PARTICIPANTS

A database containing contact information for 13,000 chemistry faculty members was updated from previous ACS need-based assessment surveys based on information obtained from departmental and institutional web pages.[29,30] The database consisted of a comprehensive list of colleges and universities from all 50 states that was sorted based on whether the university was a doctoral, four-year college, or community college. Every school's Web site was searched to update the existing list of faculty members and their contact information. All assistant professors, associate professors, professors, and instructors that could be identified by the chemistry department Web site was updated in our previously created database. For community colleges and schools that did not have specific chemistry department Web sites, the university/college directories were searched and online course catalogs were checked to attempt to identify anyone teaching chemistry. This process generated a list of roughly 13,000 chemistry faculty members from over 2,000 colleges and universities. An email was sent to all of the faculty members asking for anyone who had taught general chemistry within the past 5 years to consider participating in the full study implementation of the conceptual understanding in general chemistry survey. To protect anonymity, as required by the approved human subject's protocol for this study, none of the surveys were linked to the faculty members' names or email addresses. For reporting purposes here, participants will be identified as P#, such that P413, for example, would indicate that the participant randomly assigned to number 413. At the end of the survey, respondents were invited to participate in a drawing for an Apple iPad by leaving their email address in a link to a separate survey. Approximately 1,800 faculty members elected to participate in the ACS Conceptual Understanding survey and reported having taught general chemistry within the last 5 years. After cleaning the data set by removing participants who did not complete the two sections of the survey, there were 1,519 participants who responded to the survey, gave consent, and completed the majority of items on the survey.

Demographic Data

In the first portion of the survey, the respondents were asked to answer a series of demographic questions, which were used to describe the backgrounds of the participants. A question about the highest chemistry degree offered at the participants' institutions revealed that 32% of the participants taught at schools that offer PhD degrees, 10% at schools that offer Master's degrees, 44% at schools that offer bachelor's degrees in either chemistry or a related science, and 14% at schools that

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offer associate degrees in either chemistry or a related science. The wide range of degrees indicated that the participants represented a variety of different types of programs.

The participants also reported a wide range of years spent teaching general chemistry (Figure 1). The distribution showed

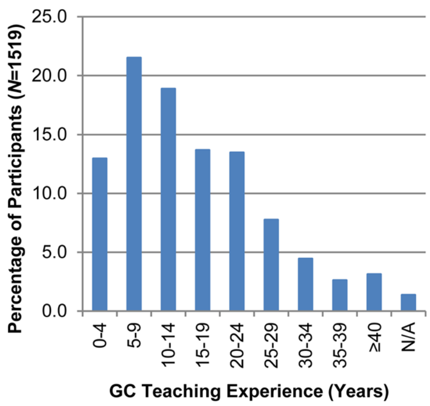

Figure 1. Distribution of the 1519 ACS Conceptual Understanding survey participants by the number of years they have spent teaching general chemistry.

that, while some of the participants were teaching general chemistry for the first time, others had been teaching general chemistry for more than 40 years. The median number of years of experience reported was 13.

The participants were also asked to report on the size of their typical general chemistry class. The majority of the participants (71%) reported class sizes smaller than 100 students with 45% of all participants reporting class sizes between 1 and 50 students.

The overall wide range of participants in the total study as well as the similarities in the distribution of participants who provided definitions suggests that the instructor-generated definitions reported here are likely provided by chemistry instructors that are generally representative of the community of chemistry educators. It is true that little is known about the "missing data" that is represented by the views of non-participants, so it is not possible to say such missing data is missing completely at random. Nonetheless, it is arguably unlikely that missing participants would hold wildly different definitions of conceptual understanding, given the variety of definitions obtained from the sample collected in this study.

■ FACULTY DEFINITIONS OF CONCEPTUAL UNDERSTANDING

Out of the 1,519 total participants who completed the majority of the survey, 1,395 instructors provided an open-response definition of conceptual understanding. All of the definitions were collated into one document and initially coded using the constant comparative method for analysis through an iterative looking back and looking forward process.[31] There is no predetermined limitation in the number of fragments that may be present in any definition. For example, the definition "understanding of the relationships of concepts to one another such that they can be applied to solve problems" (P1356) was coded as "understanding fundamental concepts", "relationships between concepts", "applying concepts", and "problem solving". Every single definition was read multiple times during the initial open coding. The first round of open codes looked for particular keywords and the meaning associated behind them. Each additional definition was analyzed with the question of how is this similar and how is this different from the definitions that came before it. The second round of coding consisted of reading for meaning and looking for inconsistencies between the ways certain ideas were coded, which resulted in 48 different codes. Within these codes, there were several overlapping ideas. A third round of coding further collapsed down the codes to 32 different codes. The 32 codes along with their frequencies can be found in Table 1. The most commonly

Table 1. Rubric Developed for Determining How Well General Chemistry Definitions Fit the Fragments of the Empirically Generated Definition[a]

Code	Frequency
fundamental/basic understanding	566
applying knowledge	544
answering questions	324
explaining concepts	261
no algorithms	251
novel/new/unfamiliar problems	244
solving problems	225
not rote memorization	211
relationships between concepts	123
no calculations/no numbers	114
predicting	111
reasoning	100
beyond math	100
why	88
macroscopic/microscopic	87
qualitative	83
big picture	82
nonmathematical	78
drawing conclusions	63
understanding the math	55
using pictures to understand	52
using multiple concepts/depictions	46
quantitative	41
visualizing the concept	39
everyday examples	34
no calculators/easy math	33
mathematical relationships	33
constructing new knowledge	31
mental models	30
critical thinking	20
general to specific understanding	19
scientific literacy	6

[a] N = 1,395; open-coded responses allowed for multiple codes per respondent.

included phrases within the open coding exercise were "understanding fundamental/basic concepts" (N = 566), "applying concepts" (N = 544), and "answering questions/solving problems" (N = 324).

The relative frequencies of codes can be viewed in a qualitative sense through the use of a word cloud as depicted in Figure 2. In a word cloud such as this, the more often a word appears as part of the definition of conceptual understanding, the larger that word appears.[32]

■ CONSTRUCTING A CONSENSUS DEFINITION

Although the initial coding scheme was able to help identify common threads present in the various definitions, the sheer

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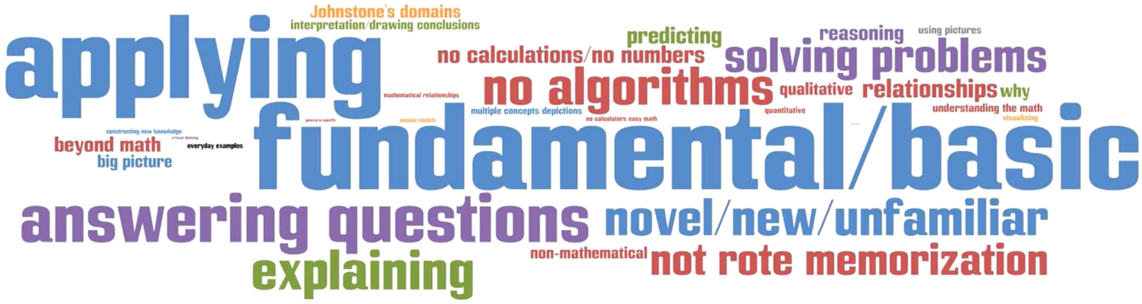

Figure 2. Word cloud depicting the prevalence of codes representing the different phrases given in the 1,395 general chemistry instructors definitions of conceptual understanding. The larger the word/phrase, the more frequently the phrase was used in the definitions. Note: color indicates how the 32 open codes were perceived to be represented in the consensus definition (transfer, blue; depth, red; predict/explain, green; problem solving, purple; translate, orange).

quantity of codes were not as useful for showing the similarities and differences between the definitions to generate a meaningful definition of conceptual understanding. A definition that requires roughly 32 components would be inherently unruly. As a result, an effort was undertaken to synthesize the 32 original fragments into ideas that incorporated conceptual understanding at a somewhat coarser level. By pairing up the similar codes, most of the 32 codes appeared to fit into 5 different ideas (transfer, depth, predict/explain, problem solving, and translate). Only two of the initial open codes, scientific literacy and using pictures to understand, were not reflected in some way in the overarching definition. Ultimately, this process led to a relatively concise, five part definition that is provided in Box 1.

Box 1. Defining Conceptual Understanding

In chemistry, there are core chemistry ideas that include theories, practices, patterns, and relationships. A student who demonstrates conceptual understanding can:

Transfer	• Apply core chemistry ideas to chemical situations that are novel to the student.
Depth	• Reason about core chemistry ideas using skills that go beyond mere rote memorization or algorithmic problem solving.
Predict	• Expand situational knowledge to predict and/or explain behavior of chemical systems.
Problem Solving	• Demonstrate the critical thinking and reasoning involved in solving problems including laboratory measurement.
Translate	• Translate across scales and representations.

Given this definition, the ACS-EI can focus on how to identify assessment that is consistent with determining the extent of conceptual understanding of a student. For conceptual understanding to be assessed, it can be expected that a test item would have to assess at least one of these five fragments. This does not mean that all items on ACS-EI conceptual exams created to date meet this criteria but rather that this definition can serve as a guide for future test development.

EVALUATION OF THE CONSENSUS DEFINITION OF CONCEPTUAL UNDERSTANDING

A key goal of this survey work is to devise an empirically derived definition of conceptual understanding as viewed by chemistry instructors. Formally, therefore, it becomes important to determine the extent to which the proposed definition successfully incorporates the variety of instructor answers contributed via the national survey. This goal was accomplished by creating a new rubric based on this definition and using it to recode all of the instructor definitions. The rubric was developed to address the fact that faculty definitions did not always contain all of the components of each fragment. It could be argued that most fragments contained two closely related ideas that, in an open ended question, faculty may not explicitly state both parts. The resulting rubric is provided in Table 2.

The method used for scoring gives the (instructor generated) definition a score of 2 when it included wording that completely matched the fragment and a score of 1 if it incorporated some of the fragment but not its entirety. Although the initial coding was used to develop the definitions for the rubric, the codes were not collapsed into the 5 fragments. Instead, each definition was carefully read, and all 1,395 definitions were coded using only the rubric. After the coding was completed, a second rater coded a random sampling of 140 definitions (~10%). Agreement was reached through a discussion of the rubric, and all of the definitions were again checked for consistency based on minor changes to the rubric. Figure 3 shows the distribution of the different definition fragments in terms of how frequently they were coded as 2 points versus 1 point.

The most common aspect of the five-part definition is the component labeled "transfer". While defining conceptual understanding, 232 instructors provided definitions that were judged to include all aspects of the transfer component, such as the definition "being able to identify the concept in new settings; to transfer the idea of the concept to a new setting" (P947, transfer score 2). In addition, another 536 instructors defined conceptual understanding using the idea of transferring knowledge from one situation to another but did not include a statement about the novelty of the situation. For example, P1348 defined conceptual understanding as "being able to both understand the theory and put it into practice" (transfer score 1). Overall, ~55% of all the definitions included some component of transfer.

The second most common definition component was the idea that students incorporate depth beyond algorithmic problem solving. Fifty participants received a score of 2 in

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Table 2. Rubric Developed for Determining How Well General Chemistry Definitions Fit the Fragments of the Empirically Generated Definition

Fragment	Score		
	0	1	2
Transfer	Definition does not contain either application of ideas or new/novel situations.	Definition includes applying knowledge or making connections between concepts but does not mention the novelty of the situation.	Definition includes both applying knowledge as well as identifying the novelty of the situation.
Depth	Definition states that conceptual understanding is memorization or definition does not mention memorization or algorithmic problem solving.	Definition states conceptual understanding is either void of mathematical calculations/memorization or discuss as needing deep understanding; both pieces are not in definition.	Definition clearly states that students need to have a deeper understanding than rote memorization or algorithmic problem solving to be conceptual; contains both a discussion of needing depth of understanding as well as going beyond memorization/algorithms.
Predict/Explain	Definition does not focus on either predicting or explaining.	Definition includes either predicting or explaining but does not include both.	Definition includes both explanations and predictions as indicators of conceptual understanding.
Problem Solving	Definition does not mention problem solving or using critical thinking to solve problems.	Definition mentions that students solve problems but does not include a critical thinking component to the definition.	Definition includes both problem solving and critical thinking components.
Translate	Definition does not mention scale or use of representations.	Definition talks about the use of representations in conceptual questions but does not mention moving between domains (scale).	Definition includes a discussion about Johnstone's domains (symbolic, microscopic, macroscopic) and relates it to scale.

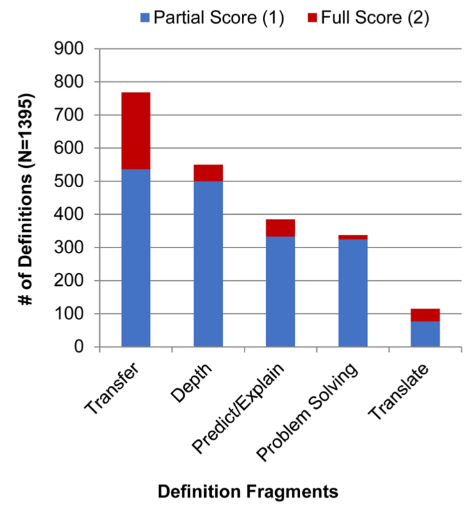

Figure 3. Number of definition fragments (by score) used to define conceptual understanding by the 1,395 general chemistry instructors who provided their definition of conceptual understanding. Each participant received a score of 0, 1, or 2 for each fragment based on how well their definitions fit the proposed definition.

this category. For example, the definition "deeper level grasp of ideas and theories [that] is not rote memorization of steps to solve a problem" (P1366, depth score 2). An additional 500 definitions included statements that conceptual understanding is not rote memorization or does not include an algorithm but did not explicitly discuss the need for a deeper understanding. For example, P975 defined conceptual understanding as "understanding the physical and chemical principles that underlie changes and properties. The counter example would be being able to simply apply an algorithm to solve a problem without knowing why or what it means" (depth score 1). Because conceptual understanding was initially discussed as not algorithmic understanding in the earlier studies, these definitions are arguably still important representations of how general chemistry faculty members define conceptual understanding, despite depth being implied but not explicitly stated.[4−6] Overall, ∼39% of all of the definitions included some form of depth in their definitions.

Participants also emphasized that conceptual understanding should include an aspect of prediction and/or explanation, such as the definition that included "ability to predict or explain observations based on well-tested hypotheses about the behavior of chemical systems" (P1484, predict/explain score 2). Both predict and explain components were included in the definitions of 52 instructors, whereas an additional 333 instructors focused on either predictions or explanations. Overall, ∼28% of the total set of definitions included explanations or predictions in their definitions.

Problem solving in general proved to be important with 325 participants mentioning explicitly the phrases "problem solving" or "solving problems" as part of their definitions of conceptual understanding. An additional 12 participants mentioned problem solving but also included a critical thinking component to their definitions. Overall, ∼24% of all the definitions included some component of problem solving.

Lastly, there was a small subset, ∼8% of all definitions, that focused on translation between the macroscopic, particulate, and symbolic domains or between representations. For example, P571 described conceptual understanding as "understanding how the fundamental interactions of the microscopic particles in a sample of matter give rise to its macroscopic properties" (translate rubric score 2). While 38 participants talked about making connections between the macroscopic and microscopic domains, an additional 77 participants focused only on one domain. For example, P358 defined conceptual understanding as "being able to visualize and interpret the behavior of matter on the molecular level" (translate score 1). In this case, the participant was identifying the molecular level (microscopic domain) and may have had an implicit expectation that this level of understanding was connected to others, but the wording provided does not actually describe such interaction between symbolic representations and the molecular level or the macroscopic and molecular levels. Thus, for the analyses here, this type of definition was scored as lacking the idea of translation between scales and results in a score of 1 rather than 2. This component of the definition has a smaller number of participants including it in their free-response definition, but this component is also supported from early literature on PNOM and conceptual thinking, so it is arguably a key aspect of the overall definition.[3,22]

There is no particular reason to expect that any individual instructor's articulation of the definition of conceptual understanding will incorporate only one aspect or all five aspects of the definition. While the examples given so far have only incorporated one component of the definition, some faculty

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members included multiple components. For example, P404 used both transfer and depth components in the definition, "Conceptual learning is applying concepts and foundational understandings to larger problems. Not simply repeating a memorized fact" (transfer score 1, depth score 2). Four of the five components were used by P23, who defined conceptual understanding as "understanding the underlying reason/theory so a student can go beyond rote calculations and use their knowledge to approach a problem worded in a new way or explain what happens without calculations" (transfer score 2, depth score 2, predict/explain score 1, problem solving score 1).

Considering whether any given definition fragment is present and summing all scores would result in a possible score range of 0 to 10. As shown in P23, the definition would have a score of 6. Over the full sample of instructor definitions, this results in a range of values that are depicted in Figure 4. Overall, the mean

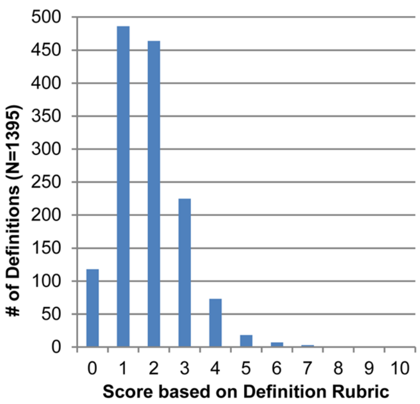

Figure 4. Total score of the conceptual understanding definitions provided by the 1,395 general chemistry instructors as scored following the rubric.

score for all instructor articulations was 1.8 ± 1.1 with a median score of 2. Although this value may seem low, there was no suggested length for the instructor created definitions, and in a survey environment, it is not surprising that many participants provided single or double component definitions.

It is also possible to collapse scores of 1 or 2 into a binary definition. In this case, a score of either 1 or 2 indicates that fragment was represented in the definition. Conversely, a score of 0 based on the rubric indicates that the fragment was not represented in the definition. As shown in Figure 5, 78% of instructors used either one or two fragments of the five-component definition. Only two instructors provided particularly complete definitions that used all five definition fragments in some way. Creating a definition from scratch is not an easy task. The definitions that were provided offer a glimpse into how faculty think about conceptual understanding, but it cannot be assumed that, because they did not discuss a fragment, that the instructors do not include that fragment in their actual working definition. We also cannot assume that the exclusion of a fragment is an indicator that the instructors do not think that the fragment defines conceptual understanding. It is also important to note that, out of the 1,395 responses that were received, only 8.5% of the provided definitions did not match any fragments from the consensus definition devised here. Of those 119 definitions, 64 of the definitions were essentially circular by stating in some way that conceptual understanding is "understanding concepts".

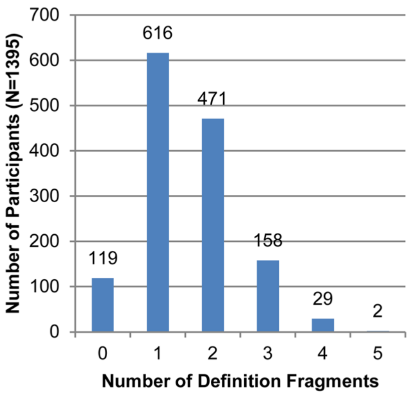

Figure 5. Number of definition fragments used to define conceptual understanding by the 1,395 general chemistry instructors who provided their definition of conceptual understanding.

■ DISCUSSION AND CONCLUSION

There are many ways in which intuitive understandings play a crucial role in the teaching and learning of chemistry. At the same time, there is also value in devising statements that can articulate shared intuitive perspectives. Doing so provides important advantages in descriptions of work done to advance student success in the classroom. The idea of defining what is expected when the phrase "conceptual understanding" is invoked represents an important example of this process.

On the basis of the results of a national survey of general chemistry instructors, it is clear that most chemistry instructors have impressions of what conceptual understanding means. Perhaps unsurprisingly, however, with a sample of roughly 1,400 such definitions, different instructors attend to different aspects of this idea. As a result, a single definition, particularly a terse, dictionary style definition, would be difficult to achieve. Initial analysis of wording used in open-response definitions was able to identify 32 words or phrases that were commonly used. This empirical analysis of instructor definitions provides a starting point, but a 32-part definition would be unwieldy and not useful. Building statements at a somewhat larger grain size provides a better alternative. While 32 different ideas were initially captured, there were underlying commonalities between many of the 32 initial codes that were used to build the five-component definition of conceptual understanding in general chemistry.

Importantly, this more manageable articulation of instructors' perceptions is able to collect a substantial majority of the free-response definitions under its umbrella. Of the 1,395 instructor definitions provided by participants in the survey, 1,277 definitions included at least one aspect of the five-component definition provided here. Thus, while it may be argued that a five-component definition is itself somewhat unwieldy, including this level of detail captured over 90% of the ways in which the chemistry education community views the idea of conceptual understanding. As such, it can be argued that the proposed definition represents as close to a consensus definition as is likely achievable. Considering all the parts, in total, is akin to stepping back and seeing the "complete elephant" in the analogy of the poem illustrated in the graphical abstract.

Having devised this definition, it is worth noting how it can play an important role in future work. From the perspective of assessment in particular, the ability to articulate specific aspects of conceptual understanding is useful in the design of test items

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intended to measure such understanding. The idea of devising specific measures of conceptual understanding as compared to more algorithmic test items has been incorporated into ACS Exams,[22] for example, and the availability of the definition devised here could lend further refinement to measures such as these. Importantly, this definition can also serve as a starting point for further elaboration and refinement of the way the term "conceptual understanding" is used. The consensus-style definition derived here provides an important connection to overall perspectives of a broadly defined chemistry education community, so moving from this empirically based definition can serve to ground future work that would be consistent with the overall expectations of that community.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: taholme@iastate.edu.

Notes

The authors declare no competing financial interest.

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