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Results of a National Survey of Biochemistry Instructors To Determine the Prevalence and Types of Representations Used during Instruction and Assessment

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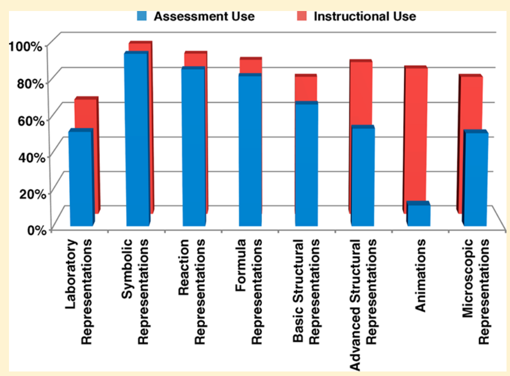
Supporting Information

ABSTRACT: Chemists and chemistry educators have long sought meaningful ways to visualize fundamentally abstract components, such as atoms and molecules, of their trade. As technology has improved, computer-based visualization methods have infused both research and education in chemistry. Biochemistry, in particular, has become highly dependent on ways that large molecular systems can be represented, and how to best focus attention on the most critical aspects of the molecular system. To better understand the current state of educational efforts related to visual literacy, a needs assessment was developed and administered to a national sample of biochemistry instructors at four-year institutions ($N = 536$) to determine the types of representations used during biochemistry course instruction and assessment. Cluster analysis was conducted on the responses to determine similar usage of representations in both instruction and assessment. A significant difference was determined between the types of representations used by instructors teaching a biochemistry survey course and a yearlong course. Implications of how these findings can influence biochemistry instruction and assessment are discussed.



KEYWORDS: *Upper-Division Undergraduate, Biochemistry, Testing/Assessment, Molecular Biology, Curriculum*

INTRODUCTION

Any number of technological advances show promise for enhancing student learning in the sciences. Nonetheless, new technology tools inevitably face barriers to widespread incorporation within educational settings.[1] In particular, the structure of education fundamentally incorporates a learning stage (often in the classroom, with or without technology enhancements) and an evaluation/testing stage which to date appears to remain far less likely to fully embrace new technology. As a result, there is a possible tension related to the incorporation of new tools, including visualization techniques in biochemistry education, between what can be done during the learning cycle and what can be incorporated into testing and assessment.

From the technology side, the American Chemical Society's Examinations Institute (ACS-EI) has begun implementing online versions of nationally normed exams. One of these exams, a laboratory exam for general chemistry, is incorporating capacities, such as full-motion video, into the test which opens new avenues for assessing students' chemistry knowledge.[2] Biochemistry would appear to be a candidate for similar enhanced tools, centered on visualization concepts such as protein structure, which could be devised using emerging capabilities in online testing. Consequently, the ACS-EI undertook a study about the role that representations play currently in the assessment of student understanding in biochemistry courses. A national survey was developed and administered to biochemistry instructors at 4-year colleges and universities across the United States. Among many possible analyses that can be undertaken with the data from this needs assessment, this report focuses on a description of biochemistry instructors' self-reported use of representations during course instruction and on course assessments.

BACKGROUND

Multiple studies have examined the connections among the "trilogy" of chemistry representation types (macroscopic, symbolic, and particulate) proposed by Johnstone.[3−7] The inherent nature of biology must also include microscopic representations.[8] While the particulate domain of the "trilogy" is often interchangeable with the term microscopic or submicroscopic,[5] in biochemistry these are two very distinct types of representations. Incorporating these various types of representations from both chemistry and biology has led to the biochemistry tetrahedron which has been used in a recent study to develop a Taxonomy of Biochemistry External Representations (TOBER) based on the observed use of representations in several biochemistry courses.[9] Equations, graphs, and tables typically found in chemistry were classified as symbolic representations, and any representation depicting chemical

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structure was classified as a particulate representation. Typical microscopic images of a cell or cellular compartments were considered microscopic representations. Finally, animations were placed at the center of the tetrahedron, as they were typically composed of multiple types of representations. While macroscopic representations were not directly observed in the biochemistry courses studied, they were part of montages observed during instruction and were considered to lie on the edges of the tetrahedron.

The representations used in biochemistry have been a major focus of research in biochemistry education in recent years.[10−17] Many of the current studies have focused on ways in which biochemistry faculty can increase students' capacity of interpreting representations, commonly referred to as visual literacy.[10−12] Some suggest doing this by increasing the complexity or the realistic nature of the representations, such as using protein crystallography images to depict protein structures in the classroom.[10,11] Other studies have focused on students' interpretation of biochemistry representations and how the interpretation influences students' understanding of the biochemical concept depicted in the representation.[13−17] Due to the importance of representations in biochemistry, the ACS-EI is interested in assessing what types of representations should be included on ACS biochemistry exams.

RESEARCH QUESTIONS

A needs assessment survey[18] was developed to determine the types of representations in biochemistry that could be included in an online ACS biochemistry exam. Data was collected with regards to biochemistry instructors' self-reported current use of various representations in biochemistry instruction and assessment. These data serve as the basis for the following research questions: (1) What representations do biochemistry instructors claim to currently use during instruction and on assessments? (2) How do biochemistry instructors believe the students interact with the representations used? and (3) Are there differences in the types of representations used based on the type of biochemistry course taught?

METHODOLOGY

The survey was developed based on the findings from individual phone interviews with 14 biochemistry instructors from various institutions across the country. The interviews consisted of questions related to instructors' thoughts on representations that should be included on an online biochemistry exam, representations used in their courses and on their assessments, and their views of developing visual literacy in their course. After a pilot test of the online survey in spring 2012, modifications were made prior to the full administration of the final survey in summer 2012. A database of biochemistry faculty e-mails was created based on information obtained from departmental and institutional web pages. A biochemistry faculty member is defined as an instructor of college level biochemistry at any faculty-level standing (tenured, tenure track, or nontenure-track). Only faculty from institutions classified as "4-year or above" on the Carnegie database[19] were sampled. Participation in the national online survey was enabled by e-mail communication to all contacts in the generated database (approximately 3,200 contacts). Demographic data collected from participants at the beginning of the survey included years teaching biochemistry, type of biochemistry course taught, size of course, and teaching practices used to teach biochemistry.

This report focuses on two specific items in the survey that query instructors' use of representations during course instruction and on course assessments. Both items required instructors to think about their usage of the 27 representations listed in Table 1. They were asked if (1) they use the representation, (2) students interpret and/or produce the representation, and (3) whether interactivity, color, or both are important to understanding the representation. Interactivity was defined prior to the questions as students' ability to interact with the representation. The representations selected to be included in this study were either found in common biochemistry textbooks and/or listed in the TOBER. The survey alphabetically presented only the names of the representations in Table 1, but these representations are organized into larger categories here (primarily based on the categories in the TOBER) that will be used as a means of discussing the findings of the study. The data was reported as "0" indicating instructors did not choose that response or "1" that instructors did choose the response. Due to the categorical nature of the data, the nonparametric Wilcoxon signed-rank statistic was used to compare instructors' use of representations between instruction and assessment.

Table 1. List of the 27 Representations Used on the Survey Organized by Representation Category

Representation Category	Type of Representation
Laboratory Representations (Set 1)	Electron Micrograph
	Electrophoretogram (GEL)
	Chromatograms
	Spectra (NMR, EPR, UV/vis)
	Cloning Vector
Symbolic Representations (Set 2)	Graphs (Kinetics, Titrations)
	Mathematical Equations
	Table of Data
Reaction Representations (Set 3)	Chemical Equations
	Reaction Mechanisms
	Metabolic Pathways
	Signaling Pathways
Formula Representations (Set 4)	Structural (Condensed) Formulas
	Nucleotide Sequences
	Amino Acid Sequences
Basic Structural Representations (Set 5)	Fischer Projections
	Haworth Projections
	Lewis Dot Structures
	Stereochemical Renderings (Wedge-Dash)
Advanced Structural Representations (Set 6)	Ball and Stick
	Protein Surface Representations
	Ribbon Diagram
	Spacefill
	X-ray Crystal Structure
	Wireframe (Skeletal Model)
Animations	Animation
Microscopic Representations	Microscopic Diagrams (e.g., Cellular Structure)

Cluster analysis was used to classify instructors into groups based on their use of representations during instruction and on assessments, respectively. Essentially, cluster analysis groups observations (i.e., biochemistry instructors) together based on the similarity of identified variables (e.g., representations used

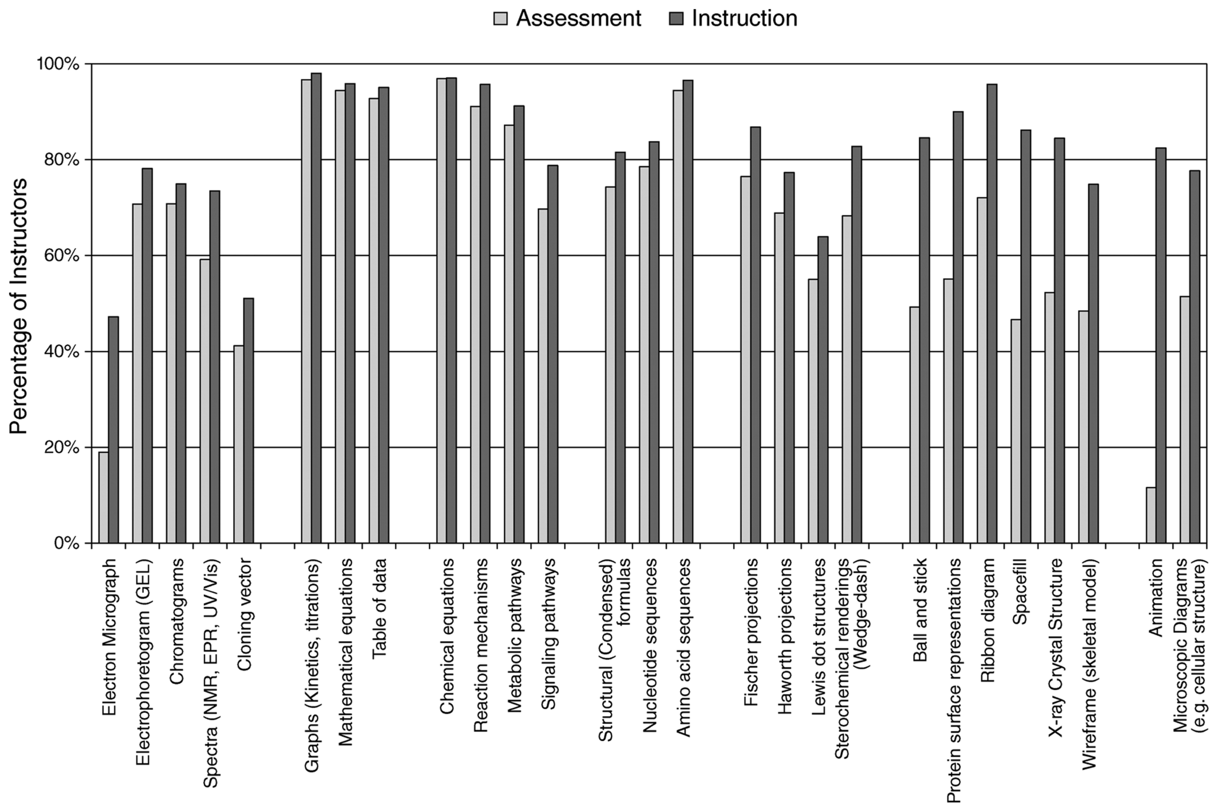

Figure 1. Comparison of biochemistry instructors' use of representations during instruction and on course assessments.

during instruction).[20] All cluster analysis was conducted using the statistical package STATA 12.0.[21] An agglomerative hierarchical cluster method was used to create the clusters by initially assigning each instructor as a cluster, followed by grouping instructors together based on their similarities until a single cluster was obtained. Using the binary data for use of representations during instruction, instructors were grouped together according to the ratio of similarity of use of the representations based on only if they used the representation (i.e., Russell similarity).[20] Therefore, the sample size of the clusters will be based on the number of instructors who use the representation and as a result will vary. In addition, the Ward's linkage procedure was used to group clusters in order to minimize the sum of squares of any two clusters. The number of clusters chosen for further analysis was decided using the Duda and Hart stopping rules where a value close to 1 is desired for the ratio of an error estimate for a proposed single cluster group relative to maintaining two groups, Je(2)/Je(1). More specifically, Je(2) is defined as the sum of squared errors within the group that is to be divided and Je(1) is the sum of squared errors in the two resulting groups and the aforementioned ratio requires a corresponding low pseudo-T^2 of both values indicating a distinct clustering.[22] Because cluster analysis is an exploratory statistical technique, logistic regression was used subsequent to clustering to determine the probability of being in one cluster over another based on the type of representation used.

■ RESULTS AND DISCUSSION

A total of 536 instructors responded to the survey (17% response rate). Overall, 75% of instructors taught in a Chemistry or Chemistry and Biochemistry Department, 9% taught in a purely Biochemistry or Biology department, and 8% taught in a Biochemistry and Molecular Biology department. Considering course structure, 53% taught one semester of a yearlong biochemistry course, 25% taught a one-semester survey course for chemistry or biochemistry majors, and 10% taught a survey course for students not majoring in chemistry or biochemistry. The remaining 12% of instructors taught a general, organic, biochemistry course, a special topics biochemistry course or did not respond to the question. Finally, a plurality of instructors (49%) have been teaching no more than 10 years, with 30% having taught 11−20 years and 21% having taught more than 20 years.

Figure 1 illustrates the comparison between the uses of a given representation during instruction and on assessments for the entire sample. Over 90% of faculty report using graphs, mathematical equations, tables of data, chemical reactions, reaction mechanisms, and amino acid sequences during both course instruction and assessment. These results are not too surprising as it would be difficult to imagine a biochemistry course where such tools were not regularly used. Also evident in Figure 1, many types of representations that can be used during lecture with PowerPoint presentations are less likely to be placed on a paper-pencil course assessment. Comparing the two contexts using the Wilcoxon signed-rank statistic for each representation reveals significant differences ($p < 0.05$) between use during instruction and on assessments for all representations except graphs, mathematical equations, and chemical reactions (Supporting Documents Table S1). Animations had the greatest difference in use between instruction and assessment based on the large effect size ($r = 0.591$).

There has been a wealth of research on students' learning from interpreting representations,[23−25] but subsequent research suggests that the process of producing representations has additional benefits.[26−29] Figure 2 provides an overview of

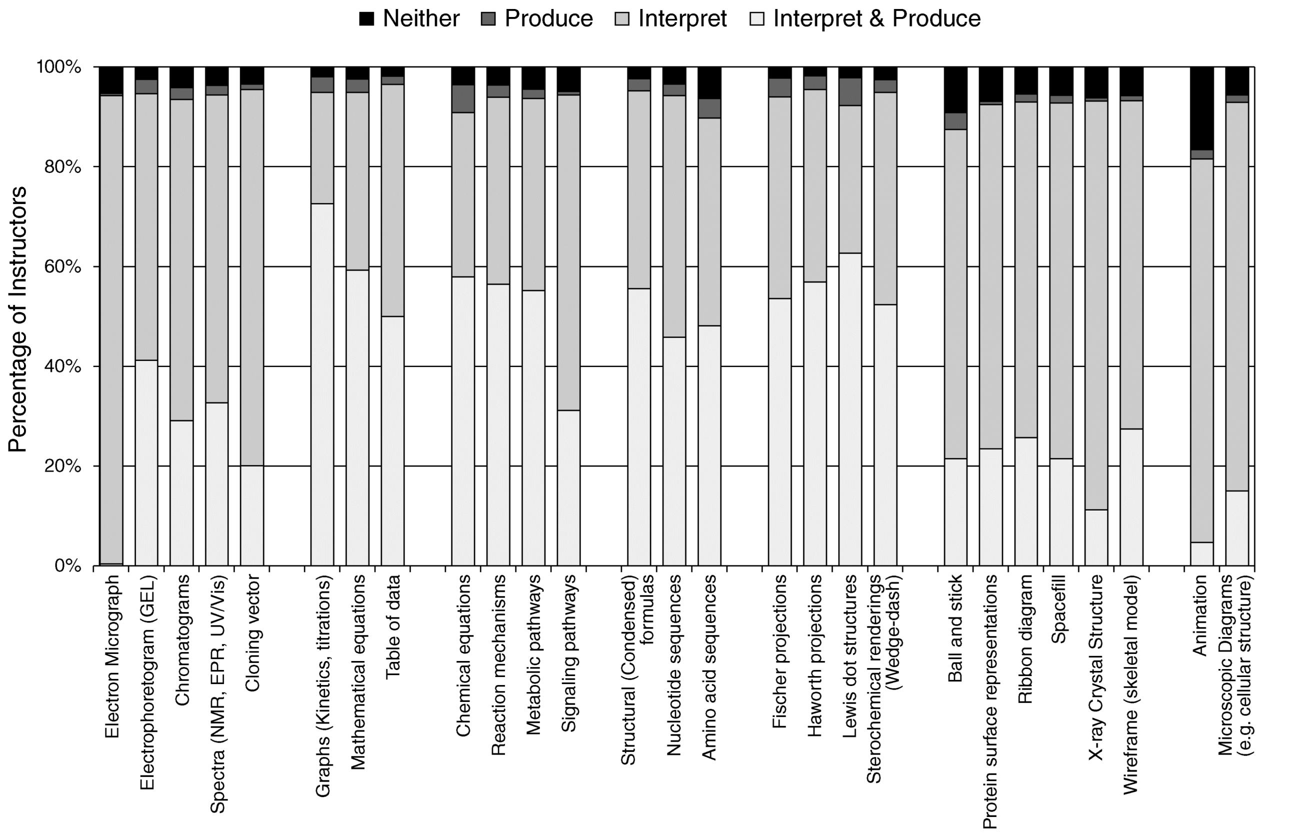

Figure 2. Comparison of how faculty report students use the representations during instruction.

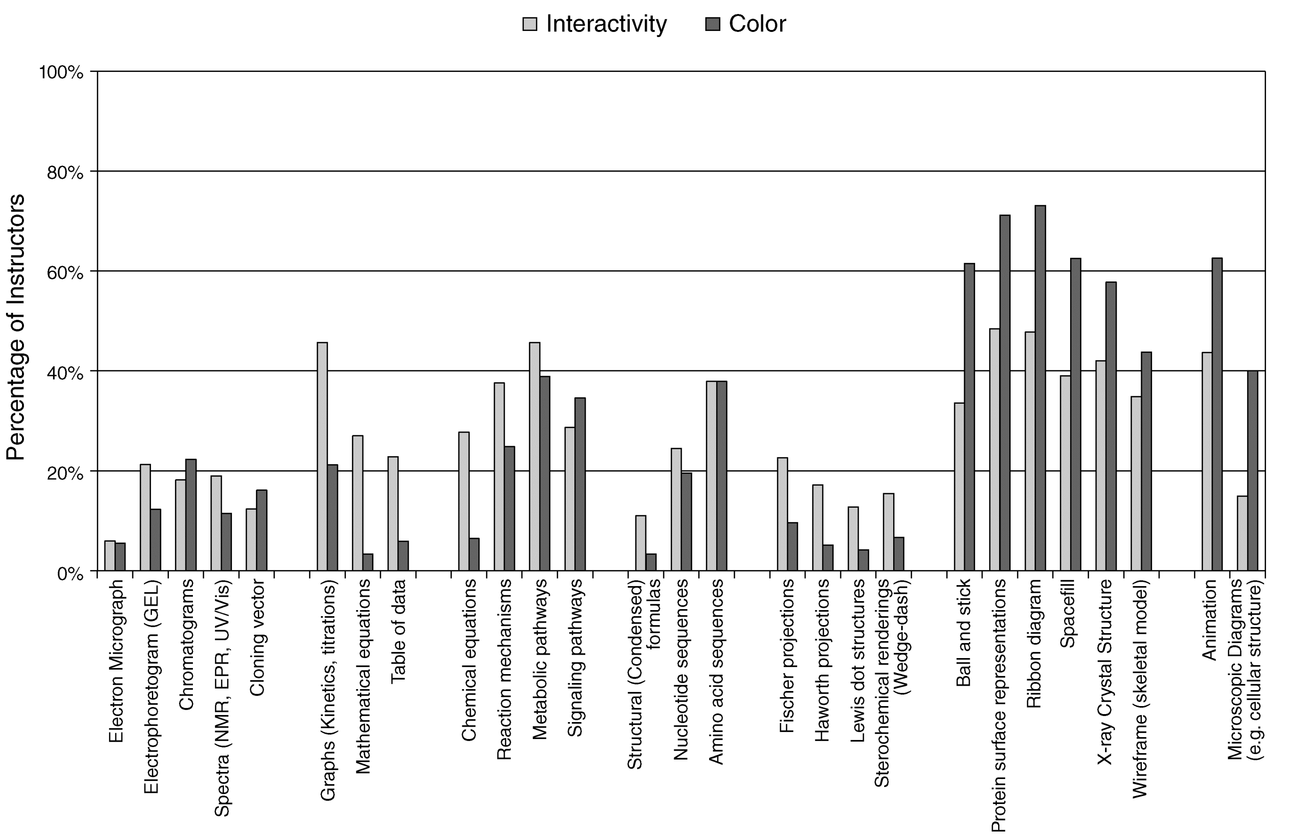

Figure 3. Comparison of faculty perceptions of the importance of interactivity and color to student understanding of the representations.

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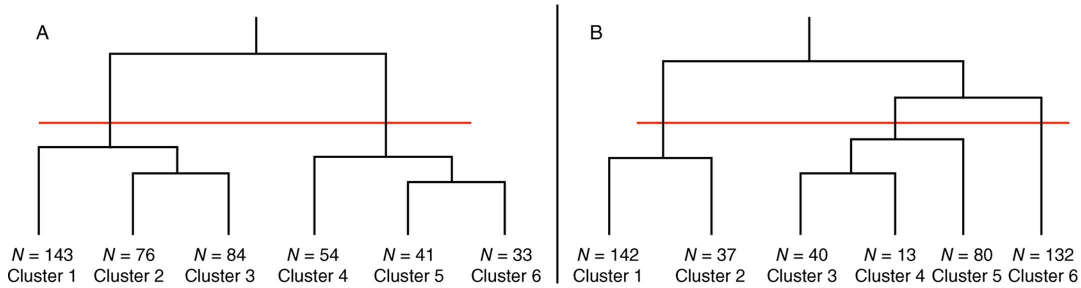

Figure 4. Dendrograms depicting the clustering of instructors based on their (A) use of representations during instruction, and (B) use of representations on assessments. The red line indicates the level at which each analysis will be discussed.

classroom use of representations according to categories of whether students produce or interpret them. According to the participants, students primarily *only interpret* laboratory representations (Set 1) and advanced structure representations (Set 6), signaling pathways, animations, and microscopic diagrams. For the remaining representations, students often *both interpret and produce* them during instruction. Quite similar results were indicated for how representations were used on assessments as summarized in Supporting Information in Figure S1.

When we look at these groupings of how instructors use representations, it seems that an apparent barrier to student production of these learning tools lies in the complexity of the representation or the means by which the representations are constructed. For example, it is not reasonable to ask a student to build a ribbon diagram from scratch, so a legitimate question can be asked as to what level of engagement with the data required for building such a representation (software and access to the protein data bank, for example) would constitute "production" of this level of visual information? Thus, it is important to recognize that the results of this survey are only meant to provide a snapshot of usage, and potentially suggest issues like this one, not to suggest current instructional strategies are in some way inadequate.

Biochemistry instructors' views toward the importance of interactivity and color as they relate to students' representational understanding are displayed in Figure 3. Note that responses indicating these traits are important are relatively low in general, but that interactivity seems to be most important (more than 30% responding) for understanding graphs, reaction mechanisms, metabolic pathways, amino acid sequences, animations, and all of the advanced structure representations (Set 6). Similarly, color seems to be most important for metabolic and signaling pathways, amino acid sequences, animations, microscopic diagrams and all of the advanced structure representations (Set 6). One way to understand these trends lies in how color is used to direct attention in complex visual representations.

Cluster Analysis of Instructors Use of Representations during Instruction and Assessment

Overall group usage patterns of representations as summarized thus far provide one level of inference about instructional and assessment practice. Nonetheless, the possibility of a finer grained analysis of representation usage may be possible based on apparent significant differences in how instructors use representations. One way to tease out usage differences from within the entire participant pool is to use cluster analysis. As an exploratory technique, any number of possible clusters might be devised, but the most compelling analysis identifies a 6-cluster model that helps differentiate how biochemistry faculty members use representations during instruction (Je(2)/Je(1) = 0.9054; pseudo-T^2 = 5.43). The percentage of faculty in each cluster who indicated using each of the representations during instruction can be found in Table S2 of the Supporting Information.

The 6-cluster model was identified based on the goodness-of-fit statistics and the sensible grouping based on instructors' usage of representations. However, further understanding can be derived by looking at the dendrogram of the cluster analysis shown in Figure 4, which depicts visually how the clusters originate from the entire sample. At the top, all data must ultimately resolve into a single cluster that comprises the entire sample. Proceeding down the dendrogram, one encounters smaller cluster groupings with increasing specificity of the similarities, but they retain the "heritage" of the higher level clusters.

For example, when we look at the different groups depicted by the red line in Figure 4A, it is possible to interpret the six clusters in the model as arising from 2 groups. Group A includes clusters 1−3 and contains participants who use nearly all of the representations during instruction. Group B includes cluster 4−6 and identifies participants who use the representations to a lesser degree. Each of the groups breaks down into the full six-cluster model (as detailed in the Supporting Information) mostly via the extent of use of Lewis dot structures or laboratory representations. It is worth noting, however, that clusters are identified by statistical similarity and are not strictly dichotomous. Thus, the majority of the instructors in Group B do use advanced structural representations although to a lesser degree, compared to instructors in Group A.

When we compare various demographic information for the six clusters, the main association ($\mathrm{Chi}^2(5) = 22.8209$ $p < 0.001$) in the data is for the type of biochemistry course taught (year long course vs survey course). Details are presented in Table S3 of the Supporting Information of how logistic regression is used to compare the instructors in each cluster to the rest of the sample. This treatment identifies Cluster 3, which is primarily distinguished by instructors not using cloning vector representations, to include participants who are 2.17 times more likely to teach a biochemistry survey course compared to a year long course, holding years teaching constant ($z = 2.988$ $p < 0.01$). Cloning vectors are often considered to be a more advanced topic that may largely account for their omission from the more time-constrained one-semester biochemistry survey course.

It is also possible to devise a 6-cluster model that groups biochemistry instructors based on their use of representations on course assessments (Je(2)/Je(1) = 0.9117; pseudo-T^2 =

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12.59) as shown in Table S4 of the Supporting Information. Again, a meaningful discussion is afforded by categorizing these 6-clusters into groups as shown on the dendrogram in Figure 4B. Group A consists of instructors who generally use all of the representations on assessments (Clusters 1–2). In this case, the remaining clusters break down further than merely using fewer representations. Instructors in Group B, from clusters 3–5, are more selective in the representations they use on assessments, primarily using symbolic, reaction, and formal representations on their tests. This is distinguishable from instructors in Group C who use all but the advanced structural representations on tests (Cluster 6). The survey does not provide detailed data about course structure, but a conjecture about such a structure that is consistent with this dendrogram is that instructors in Group B emphasize fundamental aspects of the field and spend less time connecting those fundamentals to their molecular biology ramifications: essentially, a course that emphasizes the chemistry in biochemistry.

Cluster definition for assessments also identifies a significant association (Fisher's Exact Test $p = 0.008$) between the course taught and the cluster in which instructors were assigned (Table S5) for the 6-cluster model. Using logistic regression, we find that the faculty *not* using laboratory or advanced structure representations (Cluster 5) on their course assessments compared to instructors not in Cluster 5 are 2.33 times more likely to teach a biochemistry survey course compared to a year long course, holding years teaching constant ($z = 3.117$, $p < 0.01$). This is not surprising because faculty infer additional complexity to understanding these representations (Figure 3 noted a substantial need for interactivity and color in these representations), and therefore, not including these representations on a survey course assessment could be due to the focus on understanding fundamental biochemistry concepts as opposed to more complex representations.

Comparison of Instructors Use of Representations during Instruction and Assessment

Because two different, reasonable cluster models were definable based on use of representations during instruction or during testing, it is possible to compare the cluster compositions between these two models. Doing so may provide insight into the scope of the challenge of using advanced representations in biochemistry testing. This assertion is based on a premise that if it were easier to reliably include items with complex visual elements on tests, instructors would likely do so. Only instructors included in both clusters are included in this analysis therefore the sample size has decreased. There is an obvious trend that appears when looking at a cross tabulation of group membership for the two clusters as summarized in Table 2. Instructors who tend to use all of the representations during instruction are also more likely to use all of the representations on their exams and instructors who use representations to varying degrees during instruction tend to do the same on their assessments. Recall, in particular, that the instructors in Instruction Group B did use advanced structural representations during instruction and what Table 2 suggests is that these representations are the ones that are primarily being left off of assessments for instructors in both Assessment Groups B and C.

Instructor comments from both interviews and the survey suggest that the challenge of incorporating complex visual elements of biochemistry represents an important variable. This assertion may be particularly important for instructors in

Table 2. Number of Instructors in Each Assessment Group by Their Respective Use of Representations during Instruction

	Instruction Group A *Use All Representations*	Instruction Group B *Use All to Lesser Degree*	Total Instructors
Assessment Group A *Use All Representations*	149	17	166
Assessment Group B *Use only Sets 2, 3, and 4*	40	69	109
Assessment Group C *Use all but Set 6*	88	26	114
Total Instructors	277	112	389

Assessment Groups B and C, or essentially 60% of the participants. In responding to the question "What criteria do you use to select representations for your assessments?" during the interviews instructors included the representations ability to be hand drawn, photocopied in black and white on standard sheets of paper, and ease of assessment. In addition, the survey included a question that asked instructors "What representations, if any, would you hesitate using due to concerns about computer interface?" Of the 185 responses 45% were worried about students' being able to learn a new interface for representations on an exam, and 14% were concerned with the amount of time it would take students to interact with representations on the exam. This group of observations suggests that biochemistry instructors seem to find some common concerns testing using advanced structural representations, and in this category, even with the inclusion of ideas in classroom instructions, different instructors tackle the challenges of including these representations on tests in different ways.

■ CONCLUSIONS AND IMPLICATIONS

Results of an online survey developed and administered to a national sample of biochemistry instructors indicate that the use of visual representations for biochemistry tests has lagged behind that usage in instruction. Furthermore, biochemistry instructors appear to infer a sense of complexity associated with some advanced representations. This conclusion is based on the reported need for interactivity and color for students to understand the representation. Given this apparent concern about difficult to assess aspects of representations (color and interactivity), it may be unsurprising that testing and instructional practices show substantial differences in terms of representation usage. Finally, there were also differences found between the use of representations during instruction and on assessments based on whether the instructor was teaching a full year course of a one-semester, biochemistry survey course. These conclusions are not surprising based on the course content in a survey course and the constraints of commonly used paper and pencil exams. The relative mismatch between the incorporation of representations in instruction and on tests ultimately suggests that tools need to be developed to help instructors more easily embed color and interactive representations into their exams.

Another key consideration for testing in biochemistry lies in terms of the kinds of representations that can be included on assessments. It is vital to recognize that testing representations that are unfamiliar to students will lead to measurement errors.

In other words, students who know a particular biochemical concept, but not the representation being used to prompt a response on a test, will not have their knowledge accurately tested. In addition, research needs to evaluate and explore the technology of embedding these types of representations into high stakes assessments. Will using familiar representations in high-stakes environments actually reduce the complexity of the representation? How does incorporating complex representations into an assessment influence student performance? These are examples of questions that need to be addressed as the community moves forward toward developing assessments using technology that allows the incorporation of complex representations.

■ ASSOCIATED CONTENT

Supporting Information

Results of Wilcoxon signed-rank statistic comparing biochemistry instructors' use of each representation during instruction to the use of the representation on course assessments; comparison of how faculty report students use the representations on course assessments; percentage of instructors use of representations in instruction and on assessments by cluster; percentage of instructors teaching a year-long or survey biochemistry course by the cluster they were assigned based on the representations instructors used during instruction and on course assessments. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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