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Biochemistry Instructors' Views toward Developing and Assessing Visual Literacy in Their Courses

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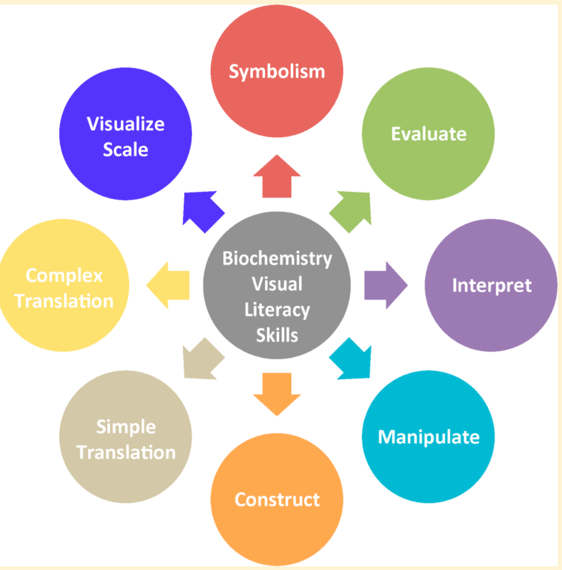
Ⓢ *Supporting Information*

ABSTRACT: Biochemistry instructors are inundated with various representations from which to choose to depict biochemical phenomena. Because of the immense amount of visual know-how needed to be an expert biochemist in the 21st century, there have been calls for instructors to develop biochemistry students' visual literacy. However, visual literacy has multiple aspects, and determining which area to develop can be quite daunting. Therefore, the goals of this study were to determine what visual literacy skills biochemistry instructors deem to be most important and how instructors develop and assess visual literacy skills in their biochemistry courses. In order to address these goals, a needs assessment was administered to a national sample of biochemistry faculty at four-year colleges and universities. Based on the results of the survey, a cluster analysis was conducted to group instructors into categories based on how they intended to develop visual literacy in their courses. A misalignment was found between the visual literacy skills that were most important and how instructors developed visual literacy. In addition, the majority of instructors assumed these skills on assessments rather than explicitly testing them. Implications focus on the need for better measures to assess visual literacy skills directly.



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FEATURE: Chemical Education Research

■ INTRODUCTION

The American Chemical Society Examinations Institute (ACS-EI) has recently initiated the release of online versions of the nationally normed exams they produce. In addition to converting standard tests to the online platform, the development of the recently released online general chemistry laboratory exam has introduced new opportunities and concomitant challenges to using representations in online assessments.[1] A future iteration of the biochemistry exam is also expected to move to an online format, in part due to the importance of the assessment of representational understanding and the opportunities that online formats have to expand representations. To prioritize possible avenues for development of new testing capacities in an online environment, a needs assessment was developed by the ACS-EI and administered to biochemistry faculty at 4-year institutions across the United States. One goal of this project was to determine which representations should be used on biochemistry assessments and in what ways. In order to meet this goal, it was important to understand in what ways instructors were using representations and what skills instructors felt were most important for students to develop in regard to representations. Therefore, the study reported here specifically focuses on the skills needed to interpret and construct representations (i.e., visual literacy[2]). The analysis includes what visual literacy skills biochemistry instructors deem to be most important to develop, how instructors report intentionally developing these skills, and whether or not instructors report explicitly or implicitly testing these skills on assessments. The results from this study not only will aid in the development of assessment items with representations but also provide valuable insight into the current views of visual literacy in the biochemistry curriculum in order to inform future professional development and research.

■ BACKGROUND

Representations are a key tool in learning and communicating chemical concepts.[3] Because of this importance, a substantial amount of research has been conducted to investigate how representations impact students' learning.[4−11] However, the necessity and technological abilities to represent complex three-dimensional biological structures in biochemistry arguably play an even larger role in developing students' visual literacy.[12−14]

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Hortin defined visual literacy as "the ability to understand (read) and use (write) images and to think and learn in terms of images, i.e., to think visually" (p 99).[2] Schönborn and Anderson[15] studied the biochemistry education literature and proposed eight cognitive skills (listed in Table 1) that they argue are central to expert visual literacy. The majority of these skills are self-explanatory from their listing. The two skills dealing with the concept of moving between multiple representations, however, merit further elaboration. The key concept is the difference between vertical and horizontal translation in visual information. This can be understood using Johnstone's levels of representation (i.e., macroscopic, symbolic, and particulate)[16] or the Taxonomy of Biochemistry External Representations (TOBER) (i.e., macroscopic, symbolic, particulate, and microscopic).[17] In this model, translating horizontally across multiple representations implies that the user (or biochemistry student) must be able to "Understand and move between multiple representations of the same system at the same level of organization" of a protein at the particulate level. This would include being able to understand and move between ball-and-stick, wireframe, and ribbon diagram representations of chymotrypsin, for example. A vertical translation of multiple representations would include being able to "understand and move between multiple representations of the same system at various levels of organization and complexity". This would include being able to interpret across the levels of TOBER and/or Johnstone's domains. For instance, biochemistry students should be able to conduct a restriction digest of DNA in the laboratory and interpret the corresponding gel (macroscopic), determine the nucleic acid sequence of the DNA where the restriction enzyme was cut (symbolic), and finally be able to look at a ball-and-stick image of DNA and interpret where the reaction is occurring (particulate).

Table 1. Expert Biochemistry Visual Literacy Skills[15]

Decode the symbolic language composing a representation
Evaluate the power, limitations, and quality of a representation
Interpret and use a representation to solve a problem
Spatially manipulate a representation to interpret and explain a concept
Construct a representation to explain a concept or solve a problem
Translate horizontally across multiple representations of a concept
Translate vertically between representations that depict various levels of organization and complexity
Visualize orders of magnitude, relative size, and scale

The original work acknowledged that some aspects of these skills overlap. Nonetheless, the skills were listed separately to assist in practical implementation of supports for visual literacy by instructors. In addition, separate listings serve to identify more reliable ways to assess each skill.[13] The skills listed in Table 1, therefore, provide the theoretical foundation for the study described herein. The role of the ACS-EI in building tests within chemistry and biochemistry provides a unique circumstance to advance this goal, but the comfort level of users of ACS Exams is an important component of their utility. Thus, it was important to first determine what visual literacy skills biochemistry faculty deem to be most important and how instructors are currently developing and assessing these skills.

RESEARCH QUESTIONS

A needs assessment survey[18] was developed to determine the types of representations that biochemistry instructors would envision being important or useful in an online ACS biochemistry exam. In order to also determine how the representations might be best used on an exam, data were also collected about current development and assessment of visual literacy skills in biochemistry courses. Analysis of this survey data allows the investigation of the following research questions: (i) In what ways do biochemistry instructors try to develop visual literacy in their course? (ii) What do biochemistry instructors view as the most important visual literacy skills to be developed and/or refined during a biochemistry course? (iii) Do instructors assess visual literacy skills explicitly or implicitly on the tests and/or quizzes administered in their biochemistry course?

METHODOLOGY

The needs assessment survey was developed in stages, with the first step being derived from individual phone interviews with 14 biochemistry instructors from 4-year colleges and universities across the United States. At the outset of the project 94 biochemistry instructors were contacted to participate in the phone interviews. This sample consisted of those instructors that had previously self-identified as interested in biochemistry education ($N = 16$) or those that on a previous survey[19] had identified as a biochemistry instructor and provided contact information ($N = 78$).

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 their assessments and their views of developing visual literacy in their courses. A copy of the interview protocol can be found in the Supporting Information. The interview notes were analyzed using a constant comparative method[20] to look for themes in the data. How the instructors viewed visual literacy was diverse, but all responses could be interpreted in line with the visual literacy skills presented in Table 1. These overall themes were then used to develop an initial survey where interviewee responses were used to construct choices to some questions and literature based responses were used in other cases. Importantly, a rewording of the skills presented in Table 1 was devised to more accurately reflect statements used by instructors who participated in the phone interviews.

The pilot survey was deployed as an online survey in spring 2012. The pilot test explicitly encouraged open-response feedback on items from the participants. Based on this feedback and on analysis of the responses, modifications were made prior to the full administration of the final survey in summer 2012. A database of biochemistry faculty e-mail addresses was created based on information obtained from departmental and institutional web pages. A biochemistry faculty member in this study is defined as an instructor of college level biochemistry at any faculty-level (tenured, tenure track, or non tenure track) from institutions classified as "4-year or above" on the Carnegie database.[21] Participation in the national online survey was enabled by e-mail communication to all contacts in the generated database (approximately 3,200 contacts) and incentivized by offering a random drawing of iPad tablet computers to those who completed the survey. Initial data collected from participants at the beginning of the survey included demographic data, years teaching biochemistry, Recent research studies have discussed the need to develop our biochemistry students' visual literacy. **Visual literacy** has been defined as encompassing "the skills required to read and write visual or symbolic language." The following questions regard the importance and development of these skills in the context of your biochemistry course and tests/quizzes.

16. Select the 3 most important visual literacy skills to be developed and/or refined during a biochemistry course.

	1st Choice	2nd Choice	3rd Choice
Construct a representation to explain a concept or solve a problem	☐	☐	☐
Evaluate the power, limitations, and quality of a representation	☐	☐	☐
Interpret and use a representation to solve a problem	☐	☐	☐
Spatially manipulate a representation to interpret and explain a concept	☐	☐	☐
Understand and move between multiple representations of the same system at the same level of organization (e.g. micro-, macro-, molecular)	☐	☐	☐
Understand and move between multiple representations of the same system at various levels of organization (e.g. micro-, macro-, molecular) and complexity	☐	☐	☐
Understanding the symbolic language composing a representation	☐	☐	☐
Visualize orders of magnitude, relative size, and scale	☐	☐	☐

17. How do you intentionally try to develop visual literacy in your course? (Select all that apply)

☐ Being explicit as to why I chose a specific representation and the limitations of each.
☐ Exposing students to representations in my course
☐ Having students build and manipulate representations.
☐ Helping students think through the representations I give them.
☐ I do not intentionally try to develop visual literacy in my course.
☐ Other (please specify) ______________________________

18. The tests and/or quizzes in my biochemistry course _____ students' visual literacy skills.

☐ assess
☐ assume

Figure 1. Items related to visual literacy on biochemistry needs assessment.

type of biochemistry course taught, size of course, and teaching practices used to teach biochemistry.

While the survey asked a wide range of questions related to biochemistry representations used during instruction and assessment,[22] this report focuses on three specific questions asking about instructors' (i) intentions to develop visual literacy; (ii) assessment of visual literacy; and (iii) views of visual literacy during course instruction. The exact statements are incorporated in Figure 1. In addition, the survey specifically defined a "representation" as a physical depiction of a phenomenon and/or object at any level of abstraction (e.g., graphical depiction of data, textbook images, and student generated diagrams). For analysis, the data were rendered as "0", indicating that instructors did not choose a particular response, or "1", indicating that instructors did choose that response. Due to the categorical nature of the data, non-parametric statistics were used to conduct all comparisons.

Cluster analysis was used to classify instructors into groups based on the methods used to develop visual literacy during instruction. Essentially, cluster analysis groups observations on the basis of the similarity of identified variables in an n-dimensional space.[23] In the analysis presented here, the observations are the biochemistry instructors and the variables are the methods instructors report using to develop visual literacy in their courses. All cluster analysis was conducted using the statistical package STATA 12.0.[24] An agglomerative hierarchical cluster method was used to create the clusters by initially assigning each instructor as a cluster, followed by grouping instructors together on the basis of their similarities until a single cluster was obtained. Using the binary data for the instructor choices about how they develop visual literacy in their courses, participants were grouped using the matching similarity method of clustering.[23] This method is based on a ratio of similarity of responses, in this case instructor use of teaching methods. The matching similarity criterion enumerates whether matches arise in the positive and negative sense; in other words a match similarity requires matching for both the set of instructional methods used and the set of methods not used. 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. In this method, 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.[25] Distinct clustering is indicated when a value close to 1 is obtained for Je(2)/Je(1) with a corresponding low pseudo-T^2.[25]

Cluster analysis is an exploratory statistical technique, so additional statistical tests were needed to determine differences in clusters. Logistic regression was used after clusters were established to determine the probability of an instructors' choices being in one cluster over another based on the

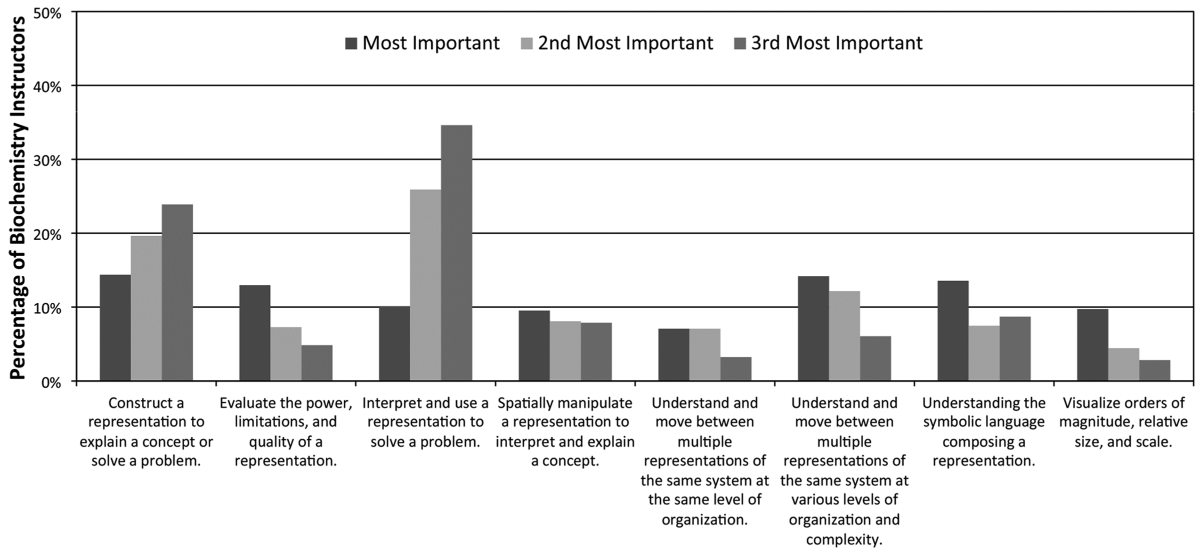

Figure 2. Biochemistry instructors' views toward the most important visual literacy skills that should be developed during a biochemistry course.

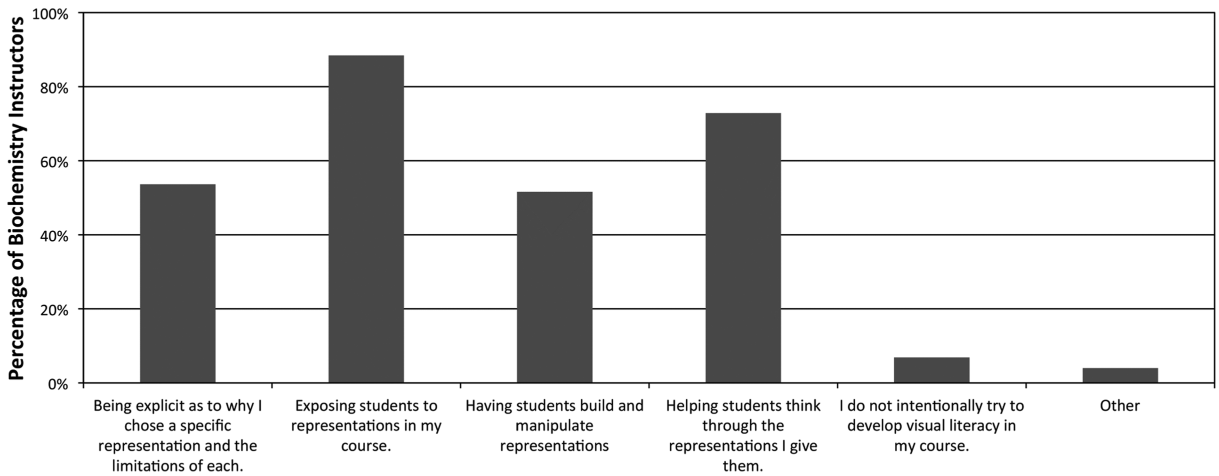

Figure 3. How biochemistry instructors' report they develop students' visual literacy skills during their biochemistry courses.

instructional methods reported by the participants. Chi-squared goodness-of-fit tests were conducted as an omnibus test to determine if the proportion of instructors in a given cluster were different from an equal distribution with subsequent pairwise comparisons using tests of proportion to determine specific significance.

■ 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. Because there is a difference of content and level of instruction for various biochemistry courses, instructors were asked to consider a single one-semester biochemistry course that they had taught when responding to the survey. In regard to this, 53% taught one semester of a year-long 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. Finally, a plurality of instructors (49%) have been teaching no more than 10 years with an additional 30% having taught 11−20 years and 21% having taught more than 20 years. Of the total sample, only the 494 instructors who responded to the questions about visual literacy will be discussed here.

The first question on the survey related to visual literacy was based on the previously defined concepts[13] noted in Table 1. As can be seen in Figure 1, instructors were provided statements describing the eight visual literacy skills and asked to rank the top three most important skills to be developed during a biochemistry course. The results for this item are summarized in Figure 2. Figure 2 suggests that the choice of most important skill to be developed varies widely, and no single skill is chosen as first by more than 15% of the participants. This initial observation emphasizes an important consideration in the teaching of biochemistry. When forced to identify the most important of these various visual literacy skills, the biochemistry community holds a quite diverse set of opinions. Having a three-choice ranking, however, allows for further analysis. Combining all three rankings suggests that two skills, (a) "Constructing a representation to explain a concept or solve a problem" and (b) "Interpret and use a representation to solve a problem", are considered key skills by a large fraction of participants. Specifically 63% and 76% of biochemistry instructors chose that these two skills should be developed within a biochemistry course.

The visual literacy skills attracting the least attention from biochemistry instructors were how to (a) "Understand and move between multiple representations of the same system at the same level of organization" and (b) "Visualize orders of magnitude, relative size, and scale" as indicated with 18% and 19% of instructors respectively choosing these overall as important. This result is interesting because studies have found that students have difficulty trying to translate across different representations of the same system[7−11] and also that scale understanding plays a prominent role in student success in chemistry.[26]

It is important to consider the possibility that the lack of consensus of instructors' choices in which visual literacy skill is most important to develop may reflect an issue with the interpretation of the question. Specifically, the instrument relies on participants' understanding of the meaning of different statements that describe visual literacy. Indeed, it has been argued that these skills are difficult to discern from one another.[15] For the data reported here, checks on participant understanding were occasionally obtained throughout the process of the instrument development. Thus, during the phone interviews, during the pilot study, and in questions posed to biochemistry instructors subsequent to the data collection, concerns about what the visual literacy statements mean have not been evident. This set of observations does not prove that all users inferred the same things from the survey items. Nonetheless, they do suggest that the statements of visual literacy skills surveyed are part of the vernacular of most biochemistry instructors.

In addition to determining what visual literacy skills the instructors deemed important to develop, the survey also asked instructors *how* they *intentionally* tried to develop students' visual literacy. Results for this item are summarized in Figure 3. Responses do not add up to 100% because participants could choose more than one response. The most common response, "exposing students to representations", was chosen by 88% of respondents. Thus, for at least some of the visual information content in the biochemistry course, a strong majority of classes report using a tacit strategy. An example of such a strategy would be including representations during a lecture or on homework assignments, but not including instructional time to explain how the information they contain can be decoded. Note that this survey did not request that instructors enumerate what content is in any of these categories, so some representational understanding may be expected as prior knowledge, for example. At the other end of the scale, 7% of instructors indicated that they do *not* intentionally try to develop visual literacy in their courses. The 4% of instructors who selected that they develop visual literacy in other ways primarily did so using computer programs and/or by building 3-dimensional models.

The final item included in the current analysis is associated with assessment or testing. Students tend to place value in those components of a course that are tested.[27] Thus, instructors' were asked whether their assessments either test or assume students' visual literacy skills. Only 43% of instructors selected that they explicitly test visual literacy skills on their assessments. The remaining 57% selected that they assume visual literacy skills rather than explicitly testing them. To the extent that developing visual literacy is a skill that instructors would like students to gain while completing a biochemistry course, it is apparent that the assessment of whether or not students are acquiring these skills is lagging. The implicit expectation that students have these skills when they take a biochemistry test also opens the possibility that an exam item is actually measuring some unknown combination of students' biochemical conceptual understanding and their visual literacy.

Cluster Analysis Based on How Instructors Develop Visual Literacy in Their Biochemistry Courses

A finer grained analysis was conducted to identify differences in instructors' intentions to develop and assess students' visual literacy skills. One way to tease out differences from within the entire participant pool is to use cluster analysis. As an exploratory technique for survey data, cluster analysis is potentially capable of establishing a wide range of possible clusters. Based on goodness-of-fit statistics for a number of possible cluster models, the most compelling analysis based on responses to the four chosen items identifies a 5-cluster model ($\mathrm{Je}(2)/\mathrm{Je}(1) = 0.7384$; pseudo-$T^2 = 52.43$). This model helps differentiate how biochemistry faculty members develop visual literacy skills during instruction and, importantly, can be understood in terms of instructional habits that appear understandable. The percentage of faculty in each cluster who indicated using each of the techniques during instruction can be found in Table 2.

Table 2. Percentage of Instructors in Each Cluster Based on Which Methods They Use To Develop Visual Literacy in Their Biochemistry Courses

Variable	Cluster 1, $N = 118$	Cluster 2, $N = 71$	Cluster 3, $N = 84$	Cluster 4, $N = 67$	Cluster 5, $N = 121$
Being explicit as to why I chose a specific representation and the limitations of each	100		100		49
Exposing students to representations in my course	100	100	100	100	73
Having students build and manipulate representations	100	100			53
Helping students think through the representations I give them	100	100	100	100	13

It is clear from Table 2 that the instructors in each cluster differ in their approaches to developing visual literacy in identifiable ways. The instructors in Cluster 1 are those that indicate using all of the techniques listed to develop their students' visual literacy skills. Instructors in Cluster 2 report doing everything except be explicit as to why they choose representations or the limitations of those representations, while instructors in Cluster 3 report doing everything except have students build or manipulate representations. Instructors in Cluster 4 only indicate exposing students to representations and helping students think through the representations given to them. The instructor behaviors in Cluster 5 are not as cleanly classified as those in the other four clusters, but the major difference is that a clear majority of instructors in this cluster do not report that they help students think through the representations given to them. The mathematical machinery of cluster analysis has thus stratified the population of biochemistry instructors represented by the sample of

Table 3. Percentage of Instructors in Each Cluster Based on Whether or Not They Test or Assume Visual Literacy Skills on Their Course Assessments

Condition	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Test	62	52	43	36	29
Assume	38	48	57	64	71

Table 4. Number of Instructors in Each Cluster Based on the Choice They Made of the Most Important Visual Literacy Skill To Develop during a Biochemistry Course

Visual Literacy Skill	Most Important					
	C1	C2	C3	C4	C5	Total
Construct a representation to explain a concept or solve a problem.	17	16	9	12	17	71
Evaluate the power, limitations, and quality of a representation.	20	6	13	11	14	64
Interpret and use a representation to solve a problem.	9	11	11	6	13	50
Spatially manipulate a representation to interpret and explain a concept.	16	8	4	9	10	47
Understand and move between multiple representations of the same system at the same level of organization.	9	4	7	4	11	35
Understand and move between multiple representations of the same system at various levels of organization and complexity.	18	11	14	10	17	70
Understanding the symbolic language composing a representation.	13	11	11	8	24	67
Visualize orders of magnitude, relative size, and scale.	13	2	13	7	13	48
Total	115	69	82	67	119	452

participants in this survey relative to the manner in which they report to develop visual literacy in their courses.

Having established clusters, it is possible to determine if there are common characteristics of the instructors that comprise them. Initial, demographic information provided by survey participants yields no significant association between the number of years teaching and which cluster an instructor is in. Similarly, the type of biochemistry course taught (year long course vs survey course) does not show any predictable pattern within this set of clusters. However, a significant association ($\chi^2(4) = 28.9844$, $p < 0.001$) was found for whether or not the instructor reports explicitly testing rather than assuming visual literacy skills on the assessments as shown in Table 3. Using logistic regression to compare the instructors in each cluster to the rest of the sample, it was found that the professors using all four instructional techniques to develop visual literacy (Cluster 1) are 2.55 times more likely to assess visual literacy skills when compared to instructors not in Cluster 1 ($z = 4.245$, $p < 0.001$). In addition, the professors in Cluster 5 compared to instructors not in Cluster 5 are 2.41 times more likely to assume visual literacy skills compared to assessing them ($z = 3.860$, $p < 0.001$). No other differences present in Table 3 are statistically significant for the current sample.

The importance the instructors placed on the visual literacy skills listed in Figure 2 was also analyzed to further characterize the choices made by instructors in each cluster. Analyzing the data in Figure 2 by clusters allows for trends to be found that would otherwise be lost in the larger sample set. One example is commensurate with what was seen in the overall data in Figure 2: the majority of instructors regardless of cluster chose "Interpret and use a representation to solve a problem" and "Construct a representation to explain a concept or solve a problem" as the second and third most important skills. Due to the similarity of these results with the earlier discussion, this data is presented in Table S1 of the Supporting Information.

Looking further, the number of instructors in each cluster that selected a specific visual literacy skill as most important to develop in a biochemistry course is shown in Table 4. The shaded boxes indicate either the cluster or the skill in which there is a significant difference relative to an equal distribution of importance based on a χ^2 goodness-of-fit test.

Looking at this data shows an important difference in what is rated as the most important skill to develop based on the cluster in which the instructors fall. There are two forms of comparison possible using chi-squared goodness-of-fit tests in Table 4: comparing relative to clusters such that an even distribution would have 20% occurrence or comparing relative to skills which would have an even distribution of 12.5%. One skill, "Visualize orders of magnitude, relative size and scale", stands out as underrepresented via either comparison for Cluster 2, χ^2 (4, $n = 48$) = 16.91, $p < 0.01$, and χ^2 (7, $n = 69$) = 23.52, $p < 0.01$, respectively. In order to determine the significant difference between the individual skills, a series of pairwise comparisons using the test of proportions were conducted. There was a significant difference between the proportion of instructors in Cluster 2 who chose "Visualize orders of magnitude, relative size, and scale" as the most important skill (4.2%) to develop relative to clusters, $z = 2.41$, $p < 0.05$, and the 2.9% of instructors in Cluster 2 who chose "Visualize orders of magnitude, relative size, and scale" as the most important skill relative to skills, $z = 2.09$, $p < 0.05$. Therefore, while no skill stood out as being most important for Cluster 2, it is shown that instructors in Cluster 2 who do everything except explain the limitations of a representation *do not* see scale as a particularly important skill to develop in biochemistry.

Additional skills were found to have significantly different proportions of instructors in each cluster: (1) "Evaluate the power, limitations, and quality of a representation", χ^2 (4, n = 64) = 8.75, $p < 0.1$; (2) "Spatially manipulate a representation to interpret and explain a concept", χ^2 (4, $n = 47$) = 10.49, $p < 0.05$; (3) "Understanding the symbolic language composing a representation", χ^2 (4, $n = 67$) = 17.66, $p < 0.01$. Pairwise comparisons were again conducted using tests of proportions to determine the significant difference in clusters. This analysis provides insight about the consistency of the cluster model. The proportion of instructors in Cluster 2 who chose "Evaluate the power, limitations, and quality of a representation" (9%)

was significantly lower than the neutral response of 20%, $z = 1.77$, $p < 0.1$. Additionally, the proportion of instructors in Cluster 3 who chose "Spatially manipulate a representation to interpret and explain a concept" (9%) was also significantly lower than the neutral 20% response, $z = 1.59$, $p < 0.1$. Recall that instructors in Cluster 2 indicated that they used all methods in their course to develop visual literacy except "explaining the limitations of representations." This analysis shows a significantly lower proportion of instructors in Cluster 2 than expected who chose "Evaluate the power, limitations, and quality of a representation" as the most important skill. This is also the case for the instructors in Cluster 3, who indicated using all methods to develop visual literacy except "having students build and manipulate representations", for which this analysis indicates that instructors in Cluster 3 also have a significantly lower proportion of instructors choosing "Spatially manipulate a representation to interpret and explain a concept" as the most important skill.

It is interesting to consider the composition of Cluster 5 specifically, because it is the one cluster with a more variable instructional composition. The proportion of instructors in Cluster 5, whose key distinguishing characteristic was that they do not report that they help students think through representations, had a significantly higher proportion (36%) than the 20% neutral response, $z = 2.06$, $p < 0.05$, when looking at the pairwise comparisons of those instructors in each cluster choosing "Understanding the symbolic language composing a representation" as the most important skill to develop. This observation seems somewhat of a mismatch between the reported objectives and practice in this course. While the survey did not provide an opportunity for elaboration of choices, this response pattern may be associated with expectations about student prior knowledge as embodied in the item measuring whether visual literacy is tested or assumed. Instructors in Cluster 5 are less likely to explicitly test visual content, but rather assume it is present in their teaching and assessment strategies. At the same time, they tend to value symbolic understanding. A possible explanation for this pairing of traits is that biochemistry instructors in this cluster expect that students arrive in their classrooms already facile with symbolic ideas taught in prior courses, so they need not explicitly teach nor explicitly test those ideas. Such an expectation may be troublesome, however, based on the previous literature that students not only have issues with the symbolic representations given in biochemistry[8−12] but also have significant trouble with the symbolic representations from previous courses such as mechanistic arrows[28] or Lewis structures,[29] both of which are necessary for understanding enzymatic mechanisms during metabolism.

■ CONCLUSIONS AND IMPLICATIONS

Results of an online survey developed and administered to a national sample of biochemistry instructors indicate that the visual literacy skills deemed overall most important for biochemistry students to ascertain are those dealing with constructing or interpreting representations to solve a problem. In developing these skills the most common instructional choice indicated that students were exposed to visual representations in a course. In terms of assessment, a majority of instructors indicated that students' visual literacy on assessments was assumed, indicating that it was not directly assessed.

There are also misalignments between the "objectives" instructors believe to be most important in developing and how they report developing and assessing these skills apparent in the teaching of biochemistry. Even though the idea of constructing and using representations to solve problems was routinely chosen among the important skills for students to obtain, only 51% of instructors indicate that they have students build and manipulate representations. Only 43% of instructors report explicitly assessing visual literacy skills in their courses. This set of observations suggests that the use of visual representations in biochemistry courses remains a challenge, and the challenge is particularly critical in terms of testing. In light of these results, it may be that efforts to enhance the ability of biochemistry instructors to include visualization capabilities in testing would be an important pedagogical development for the field.

It is also worth noting that 58% of instructors largely align the skills they deemed most important with how they intended to develop visual literacy in their course. Of these, there was a group of 118 instructors (Cluster 1 in the cluster analysis) who in addition to dedicating significant instructional resources to their objectives of having students use visual representation were also more likely to report explicitly testing visual literacy on exams. These instructors not only report use of evidence-based approaches in their classroom in regard to representations but also explicitly align objectives and assessments, which is also an evidence-based approach to teaching. The results of this study could be further validated through explicit observations of the instructors in the other clusters in order to more fully characterize the visual literacy practices in biochemistry courses. Such a study would augment the current measurements of the degree to which the instructors in Cluster 1 actually use reform-based practices. For instance, is Cluster 5 acting as a catch-all or is it classifying instructors who lack in various areas of pedagogical knowledge? Additional studies could also look more closely at the use of representations on assessments in biochemistry and how these uses relate to how instructors classify as to explicitly or implicitly assessing visual literacy.

To consider the implications of these findings, it has been proposed that visual literacy needed to understand biochemistry representations and content knowledge in biochemistry are interdependent.[15] If this assertion is accurate, instructors need to emphasize that, when using representations in a biochemistry course to explain a concept, there is more to understanding the representation than just knowing what it represents. An instructor who believes one or more of the visual literacy skills listed in Table 1 are important for students to develop may wish to be intentional in trying to develop those skills in the course. Exposing students to representations is quite common and certainly represents a first step in developing visual literacy. For meaningful learning to arise, however, it should not be the last. Having an open discussion with students about factors such as (a) what is depicted in the representation, (b) what is not pictured, (c) the limitations, and (d) why the representation was selected to explain a particular concept all are teaching strategies that serve to advance students' visual literacy.

Another key consideration is the fact that assessment is a key component of learning.[30,31] If material is not tested, students do not place value on that material[27] and learning is less likely to occur. Instructors who have made developing visual literacy an objective for their course and have used techniques to develop the skills need to assess whether or not students have developed the skills.[32] Because conceptual understanding and visual literacy are interrelated, it is often hard to differentiate which objective is being measured within a single test question. However, if questions are used where students evaluate or synthesize a representation, this may lead to a direct measure of students' visual literacy.

The ability to assess and measure visual literacy appears to be an area in need of further research, as greater importance is placed on both assessments and representations. The findings from this study will allow future biochemistry exam developers working with the ACS-EI to determine how to utilize representations on future exams. For instance, because the construction and interpretation of representations to solve problems were rated the most important skills, committees can ensure that they incorporate items that require students to use representations to solve a problem. In addition, as online versions of tests become capable of utilizing enhanced visualization capabilities, test development can seek to leverage such new capacity to improve the caliber of measurements used to assess student knowledge of biochemical representations.

■ ASSOCIATED CONTENT

Supporting Information

The interview protocol that was used to collect data to inform the development of the online survey, which is the source of the data analyzed in this manuscript; the table presenting the percentage of instructors in each cluster who selected a specific visual literacy skill by importance. This material is available via the Internet at http://pubs.acs.org.

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Notes

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