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

Kimberly J. Linenberger
Iowa State University

Thomas Holme
Iowa State University, taholme@iastate.edu

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Abstract
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Keywords
Upper-Division undergraduate, biochemistry, testing/assessment, chemistry education research

Disciplines
Curriculum and Instruction | Higher Education | Other Chemistry | Science and Mathematics Education

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

Kimberly J. Linenberger† and Thomas A. Holme*

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

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.

KEYWORDS: Upper-Division Undergraduate, Biochemistry, Testing/Assessment, Chemistry Education Research

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. 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 literacy3). 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. Because of this importance, a substantial amount of research has been conducted to investigate how representations impact students’ learning. 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.
Horton 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). Schonborn and Anderson15 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).

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-EL 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 survey18 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 survey19 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 method20 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.**

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

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.](dx.doi.org/10.1021/ed500420r J. Chem. Educ. 2015, 92, 23–31)
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 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 system7-11 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 instructors’ 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 (Je(2)/Je(1) = 0.7384; pseudo-T² = 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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cluster 1, N = 118</th>
<th>Cluster 2, N = 71</th>
<th>Cluster 3, N = 84</th>
<th>Cluster 4, N = 67</th>
<th>Cluster 5, N = 121</th>
</tr>
</thead>
<tbody>
<tr>
<td>Being explicit as to why I chose a specific representation and the limitations of each</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>49</td>
</tr>
<tr>
<td>Exposing students to representations in my course</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>73</td>
</tr>
<tr>
<td>Having students build and manipulate representations</td>
<td>100</td>
<td>100</td>
<td>73</td>
<td>53</td>
<td>13</td>
</tr>
<tr>
<td>Helping students think through the representations I give them</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>13</td>
</tr>
</tbody>
</table>

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...
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. Moreover, 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 when compared to instructors not in Cluster 1 ($z = 2.41, p < 0.05$), and the 2.9% of instructors in Cluster 2 who chose “Interpret and use a representation to solve a problem” as the most important skill to develop relative to clusters, $z = 2.9\%$, $p < 0.05$. 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 significant differences in proportions of instructors in each cluster: (1) “Evaluate the power, limitations, and quality of a representation”, $\chi^2(4, n = 64) = 8.75, p < 0.1$; (2) “Spatially manipulate a representation to interpret and explain a concept”, $\chi^2(4, n = 47) = 10.49, p < 0.05$; (3) “Understanding the symbolic language composing a representation”, $\chi^2(4, n = 67) = 17.66, p < 0.01$. 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%)
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 material27 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 visual literacy on exams, 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.

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.
the skills need to assess whether or not students have developed the skills.22 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 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.

AUTHOR INFORMATION

Corresponding Author

*E-mail: taholme@iastate.edu.

Present Address

†(K.J.L.) Department of Chemistry and Biochemistry, Kennesaw State University, Kennesaw, Georgia 30144

Notes

The authors declare no competing financial interest.

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