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ASSESSMENT TOOLS AND DISCUSSION

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Meeting report: BioMolViz workshops for developing assessments of biomolecular visual literacy

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Abstract

While molecular visualization has been recognized as a threshold concept in biology education, the explicit assessment of students' visual literacy skills is rare. To facilitate the evaluation of this fundamental ability, a series of NSF-IUSE-sponsored workshops brought together a community of faculty engaged in creating instruments to assess students' biomolecular visualization skills. These efforts expanded our earlier work in which we created a rubric describing overarching themes, learning goals, and learning objectives that address student progress toward biomolecular visual literacy. Here, the BioMolViz Steering Committee (BioMolViz.org) documents the results of those workshops and uses social network analysis to examine the growth of a community of practice. We also share many of the lessons we learned as our workshops evolved, as they may be instructive to other members of the scientific community as they organize workshops of their own.

KEYWORDS

assessment and the design of probes for student understanding and learning, cooperative/collaborative education, molecular visualization, visual literacy

1 | INTRODUCTION

A student's ability to understand and interpret visual images and models of biomolecules is critical to understanding molecular function.[1,2] Consequently, biomolecular visualization (BMV) has been recognized as a threshold concept that plays a key role in developing expertise in the field.[3] However, students face myriad challenges when approaching BMV. The appearance of rendered images of biomolecular structures can vary greatly as students are presented with representations of cell membranes, organelles, macromolecules, and biochemical pathways. Textbooks depict these structures as two-dimensional objects, yet rarely is there any instruction on relating these two-dimensional images to the three-dimensional and dynamic nature inherent to biomolecular processes.[4] And yet, a deep understanding of fundamental biochemical concepts (e.g., structure–function relationships) requires knowledge of three-dimensional structure. Therefore, students must be able to visualize and extract meaning from these representations. This can be problematic, however, when students apply, unguided, their own prior conceptions to the interpretation of the image.[5]

The challenge of addressing students' conceptions of images points to a need for explicit instruction in the interpretation of visual images. However, this type of guidance in the process of building visual literacy is rare. Although biochemistry instructors report exposing students to visual images as part of their instruction, fewer indicate that they guide students through interpretation of the images they show. Consequently, over half of the biochemistry instructors surveyed indicate that their tests and quizzes *assume* visual literacy skills rather than *assess* them.[6] However, students do not always understand images in the way in which the instructor assumes.[7–11] Indeed, studies comparing the ability of novices and experts to glean information from visual images have confirmed this disconnect, as novices simultaneously grapple with both the concept and the mental image, often resulting in misconceptions of both.[12]

Cognitive load theory suggests that learners can only retain seven cognitive elements simultaneously in their working memory, while operating on just two to four elements at one time.[13] It may be that experts are able to chunk information, such that the single cognitive element is a rich combination of many different concepts. For example, an expert may group all of "protein structure" into a single cognitive element because, for them, it encompasses the entirety of amino acid sequence, N- and C-termini, helices, parallel, and antiparallel beta sheets, loops, disulfide bonds, hydrophobic cores, and so on. For the novice, however, each of these concepts would be a unique element and overloads working memory. Novices also have limited prior knowledge on which to build and are frequently mastering new vocabulary along with the concepts, all of which leads to further cognitive overload.[14]

To facilitate the transition of a novice student learner toward expert-level knowledge in BMV, instructors should provide explicit and intentional training in BMV literacy.[15,16] Unless this ability is explicitly assessed, there remains the possibility that questions that simultaneously test content knowledge and visual literacy will conflate these discrete abilities.[15] Our group, BioMolViz (BioMolViz.org), is a nationwide community of practitioners dedicated to this explicit instruction of biomolecular visual literacy.

2 | BIOMOLVIZ

Founded by Paul Craig at the 2013 ASBMB Special Symposium titled Student-Centered Education in the Molecular Life Sciences (hosted at Seattle University by Jenny Loertscher and Vicky Minderhout), BioMolViz began with six members, each from different institutions across the country, including faculty of all ranks and from both large research universities and primarily undergraduate institutions. Over the past 7 years, our group's efforts have reached over 100 biomolecular life scientists, including an expansion of the original Steering Committee to 14 total members (four of whom have since left to pursue other projects).

2.1 | The biomolecular visualization framework

The first product of BioMolViz was the BMV Framework, a tool built with collaborative input from the biochemistry and molecular biology (BMB) community[1] (Figure 1(a)). The Framework, available at BioMolViz.org, is an assessment tool in which biomolecular visual literacy has been unpacked as a series of 12 Overarching Themes, 27 Learning Goals, and 119 Learning Objectives. These Themes, Goals, and Objectives are solely focused on the ability of students to view, understand, interpret, and produce biomolecularly-relevant visual images, that is, *biomolecular visual literacy*. Importantly, this ability is distinct from using such images to probe students' content knowledge. Learning Objectives are further delineated by level of expertise (Novice, Amateur, and Expert). For example, the Overarching Theme of "Structural Model Skepticism" comprises three Learning Goals; Learning Goal SK2 has been expanded to demonstrate the three Learning Objectives within SK2 (Figure 1(b)). In this way, a BMB educator can find specific learning objectives to explore students' biomolecular literacy,

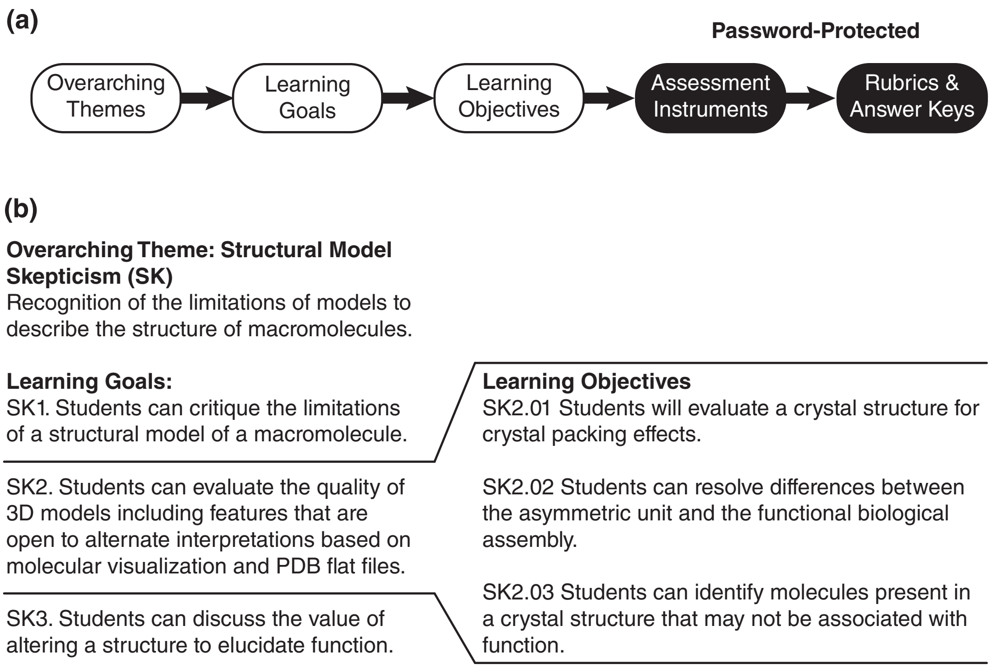

FIGURE 1 Organization of the biomolecular visualization framework. (a) Twelve overarching themes are unpacked into learning goals and learning objectives. (b) An example of the unpacking of the overarching theme structural model skepticism (SK) into three learning goals, one of which (SK2) is further unpacked into three learning objectives (SK2.01–SK2.03). The full framework can be viewed at BioMolViz.org

which is distinct from their ability to infer content from such images. The intention of the Framework is to empower instructors to apply backward design in the development of the BMV assessments they produce—setting goals before designing curricula and assessment tools.[17,18] Considering the desired learning objectives allows the instructor to produce targeted assessments that better achieve course aims.

Our next goal was to use the Framework to define competencies and create assessment instruments for educators to probe students' visual literacy. Rather than develop these instruments internally, we created workshops to crowdsource their development with the expectation that scrutiny by a larger community might generate instruments that were more broadly applicable.

2.2 | Expanding the network through NSF-funded workshops

With support from the National Science Foundation (IUSE #1712268), we hosted a series of nationwide workshops from July 2017 through January 2019 dedicated to the expansion of instruction in visual literacy. These 1-day workshops had three goals:

1. Collect common student misconceptions that arise from—or could be solved by—visual representations.
2. Collaboratively construct assessment instruments to support the explicit instruction of visual literacy.
3. Build a diverse network committed to explicit instruction of visual literacy.

This Meeting Report shares the activities from these workshops.

Multiple complementary methods were used to recruit a diverse pool of BMB instructors to the NSF-IUSE-funded workshops. A letter soliciting participation was sent to a list of over 560 practitioners across 37 institutions. We also promoted our workshops in an *ASBMB Today* essay describing the project,[19] along with a 4-month *ASBMB Today* advertisement. To recruit participants from historically underrepresented groups, we advertised in monthly emails and on the website of the nonprofit DiverseScholar, which publishes the MinorityPostdoc.org career portal and maintains an email list of more than 1000 diverse postdoctoral fellows.[20] An underrepresented minority audience was also reached through promotions at the 2017 annual conference of the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) and the 2017 Annual Biomedical Research Conference for Minority Students (ABRCMS). The majority of participants reported hearing about the workshop principally via email, either from the workshop leaders directly or forwarded to them by a colleague.

Prior to the workshops, BioMolViz was invited to lead a session at the 2017 ASBMB Transforming Education Symposium at the University of Tampa (hosted by Michael Carastro). We used this session as a way to (a) disseminate our group's objectives, (b) begin collecting crowdsourced competencies for Learning Objectives from the Framework, and (c) solicit input to drive activities at our workshops. We introduced the Framework through a sorting exercise that used the assessment terms in our Framework hierarchy. We described the "competencies" that participants would articulate *en route* to writing assessments and then instructed teams of participants to write and revise competencies for a specific Learning Objective from the Framework. The full group then discussed the process of collaborative refinement of a competency and how crowdsourcing assessment instruments leads to a more robust product. The session concluded with a discussion of successful workshop features to apply to our upcoming events. This meeting provided excellent guidance as we laid the groundwork for our first NSF-sponsored workshop in January 2018.

3 | ASSESSING THE EFFICACY OF THE 2018 BMV WORKSHOPS

By the end of our workshops we were able to use products from preworkshop homework, products from the workshops themselves, postworkshop surveys, and social network analysis (SNA) to assess our progress toward meeting our workshop goals. For details of each of the workshops, consult Supporting Information S1.

3.1 | Goal 1: Collect common student misconceptions that arise from—or could be solved by—visual representations

Participants were quick to offer misconceptions and misunderstandings that they have witnessed in their classrooms. Through preworkshop homework and in-workshop activities, we have assembled 77 misconceptions and/or misunderstandings that either arise from—or could be potentially rectified by—biomolecular visual representations. Many of these were identified by instructors at different institutions and across different workshops suggesting that existing resources (e.g., textbooks, web resources) are unclear or misleading and/or instructors do not sufficiently probe students' biomolecular visual literacy to discern whether their students do, in fact, see what the representation(s) are meant to convey. This speaks directly to concerns about inadvertent misconceptions that oversimplified textbook representations may create (see "Workshop 1" in Supporting Information S1). We are compiling these misconceptions and misunderstandings for a manuscript currently in preparation.

3.2 | Goal 2: Collaboratively construct assessment instruments to support the explicit instruction of visual literacy

At the conclusion of the workshop series, we had collected over 180 participant-created instruments for the assessment of biomolecular visual literacy. Following an ancillary workshop to develop a workflow (vide infra "Additional Products"), several of these had been mapped back to Learning Objectives from the Framework. We also solidified a clear workflow for moving draft assessment instruments through a process of revision and annotation for sharing more broadly with the BMB education community. We found broad support for the Framework across all five workshops and the two ASBMB Symposium workshops, suggesting that the collaborative development of the Framework resulted in a widely-accepted tool for BMV assessment. With support from an NSF Research Coordination Networks in Undergraduate Biology Education (RCN-UBE) grant, we are currently preparing a web portal for the distribution of these assessment instruments to members of the community.

In a free-response postsurvey question, approximately three quarters of participants commented on the value of collaborating with members of the community. Value in team-based writing of assessment questions through iterative processes has been well-documented, and methods for collaborative creation of such tools has been described in natural science and medical fields.[21–24] In the area of BMV, collaboratively-designed visualization activities were employed to assess fundamental student misconceptions about the nature of the alpha-helix. Through a workshop run by Loertscher et al., prior to our grant activities, faculty collaboratively designed visualization activities to address these misconceptions that improved student performance on post-tests.[25] However, even in the highest-performing classes only 80% of students were able to correctly answer all three questions about the alpha-helix, indicating the need to develop additional activities to better teach visualization skills. This also emphasizes the need for validation of the assessment instruments created through our BMV workshops.

Postworkshop surveys demonstrated participants' gains in awareness of visual literacy and the need for assessment instruments in biomolecular visual literacy. In response to the prompt: "Briefly list or describe what you have gained and/or contributed by attending this workshop," nearly half of all participants ($N = 55$) noted that they gained a better understanding of how to create assessments to test students' understanding of molecular visualization. For example, one participant said, "I have gained a better understanding of what molecular visualization skills a student should have and how to create assessment questions that targets [*sic*] those visualization skills." A significant number of respondents indicated that a longer workshop format would have been more productive, with several comments suggesting the need for an additional day of work added to the schedule.

Responses also lauded the sharing of projects and resources for BMB instruction. For instance, one survey response mentioned the various pedagogical resources that were acquired through the workshop: "I also made valuable connections for sharing teaching resources such as... videos and pre- and postassessments, as well as for incorporating research into undergrad lab courses." The sharing of resources happened organically during the workshops, and, in response, we created shared documents for participants to add BMV-related links. We recommend that workshop organizers consider resource exchange preworkshop and encourage this type of collaboration with a method to share tools already in place.

3.3 | Goal 3: Build a diverse network committed to explicit instruction of visual literacy

3.3.1 | Expanding the BioMolViz network

Our initial group of six Steering Committee members from the 2013 inception of BioMolViz has now expanded to the 10 authors of this manuscript, three of whom joined as a direct result of these workshops. Our workshops brought biomolecular visual literacy to 62 new individuals. We reached another 43 individuals through invited sessions to the 2017 and 2019 ASBMB Transforming Undergraduate Education Meetings (in Tampa and San Antonio, respectively), bringing our total community of practice to over 103 unique individuals representing 86 institutions across 28 states. Intentional recruitment and selection led to a demographically diverse set of participants across race and ethnicity, gender, position, rank, and experience. We also recruited with an eye toward institutional diversity, with 10 minority-serving institutions and three community colleges among the 86 total institutions.

Diversity of participation is only as strong as the quality of interactions within the group. In postsurveys, a third of all respondents mentioned increasing their professional community in response to the prompt, "Briefly list or describe what you have gained and/or contributed by attending this workshop," crediting the network with promoting additional gains related to their teaching. Specifically, participants perceived the workshop as an "excellent networking opportunity" where they could connect with "an important network of people who are interested in biochemistry education." As a result of making connections with new colleagues and working in close collaboration with others, participants indicated that they learned new instructional techniques and exchanged teaching resources. As responses to open questions do not faithfully capture the myriad contacts among workshop participants, we sought methods to examine the extent of the network our workshops produced.

3.3.2 | Using SNA to study the professional network

A major aim of our NSF-IUSE grant was to create a national community of educators dedicated to continuing the task of developing reliable and valid BMV assessments for use by instructors. As a professional development opportunity, our workshops brought together diverse groups of instructors to create a growing professional learning community that, prospectively, enhanced their social capital (i.e., their professional ties to access valuable information, knowledge, advice, support, and resources). This includes specifically recruiting from minority-serving institutions (i.e., Morgan State University [also a workshop host], Spelman College, Meharry Medical College, National University) to broaden participation in our community of practice. We therefore sought a method to evaluate the network we were building through our workshops.

Social Network Analysis (SNA) aids researchers in understanding the connections formed via professional development opportunities.[26–28] SNA is a quantitative and visual approach to examining the relationships between individuals (or nodes) in a social milieu. The graphic display of the network (a "sociogram") serves to illuminate how nodes are connected and the role nodes play within the network.[29] Understanding networks is important because instructors rely on their social capital to improve their teaching practice[26,30] and student learning outcomes.[31] Drawing on the body of research above, we utilized SNA to understand the span and scope of our growing network.

Using workshop attendance rosters, the sociogram presented in Figure 2 captures some of the following characteristics of the network: (a) the geographic diversity across the BMV community, (b) the geographic diversity of instructors within each workshop, and (c) the role instructors play across the network. For example, nodes that appear toward the center of the sociogram represent participants who attended more than one workshop and thus have higher *degree centrality* or connections to other nodes. These individuals play an important role in brokering ties between nodes and acting as conduits of information and resources across the network. Using degree centrality as a metric, we identified participants who later joined the BioMolViz Steering Committee. Additionally, the sociogram taught us that workshops held in partnership with national societies (i.e., those in Tampa and San

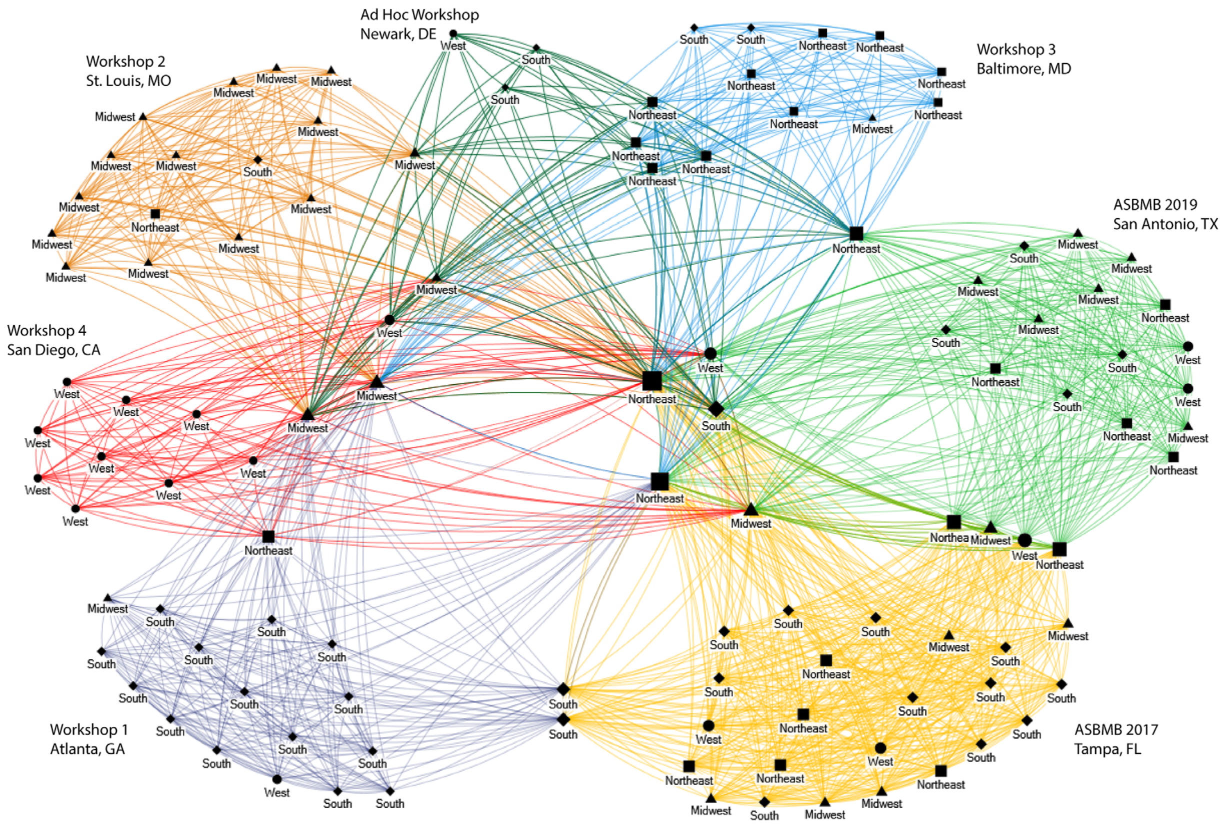

FIGURE 2 Sociogram of workshop participants generated via NodeXL using the Harel–Koren fast multiscale layout algorithm. The nodes indicate the regional location of a given participant's home institution; diamond = South, triangle = Midwest, circle = West, square = Northeast. Symbol size is proportional to degree centrality. Larger, more centrally located nodes indicate individuals with a higher degree centrality; these individuals attended more workshops and are therefore connected to more of the network

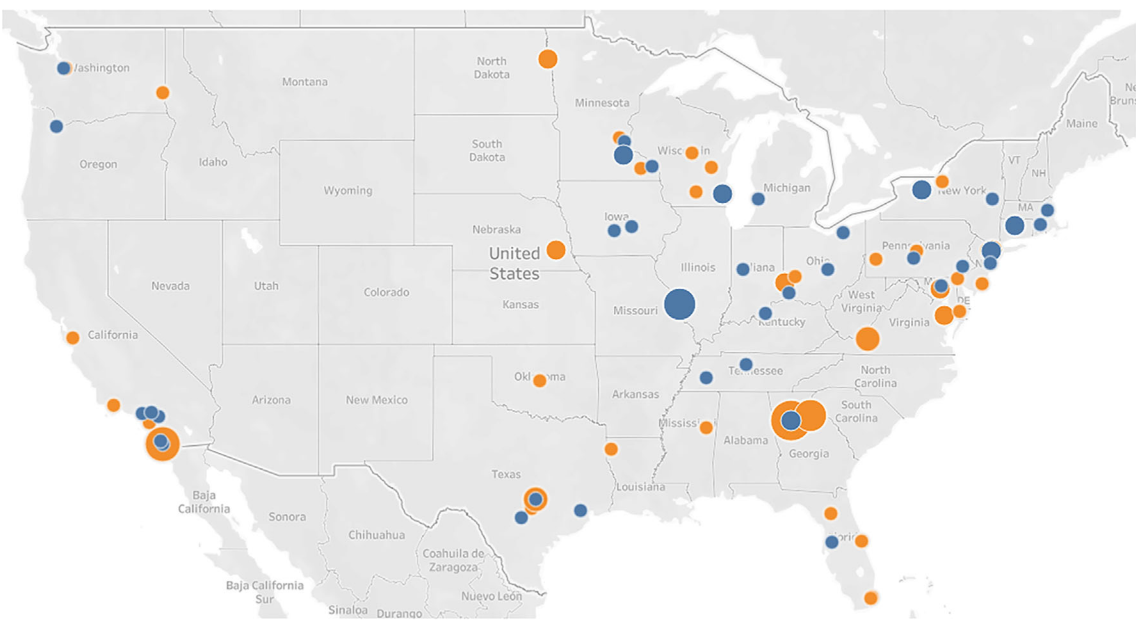

FIGURE 3 Map of workshop participants' institutions. Blue dots denote participants from private universities/institutions; orange dots denote participants from public universities. Symbol size is proportional to the number of participants from a given institution

Antonio) attract a more geographically diverse group of attendees than regional locations. Diversity of geography and institution type are also indicated on the accompanying map (Figure 3). This information will be used to drive strategic plans for future workshop locations and recruitment efforts.

As we prepare for the next round of workshops, we will continue to use SNA to examine the diversity of our participants, to recruit particularly engaged individuals (with higher degree centrality) to leadership positions within the group, and to expand to an evaluation of gender, race/ethnicity, discipline, and institution type. Key questions for future analyses include (a) how sustainable are the connections between participants over time? (b) what social capital gains do participants glean from the network?, and (c) how is the network evolving in terms of size and diversity?

3.4 | Additional products

By the end of the workshops, sufficient resources remained to support a fifth workshop (Supporting Information S1). The goals of this ancillary workshop were to polish assessments and, in the process, to create an improved workflow for revision based on participant feedback from the previous workshops. The group work and conversations resulted in three major outcomes:

1. *Stepwise review protocol*: The Steering Committee used the methods established in this workshop to outline a stepwise protocol that can be used to perform a final review of peer reviewed assessments. This method, which we will formally pilot at upcoming workshops, includes a walkthrough of the revision process for a completed assessment, as well as a stepwise protocol for improving assessment wording and image clarity.
2. *Accessibility*: Some participants identified assessments that may not be accessible to colorblind individuals. The Steering Committee integrated a step that evaluates images using a color blindness simulator in an effort to improve accessibility.[32]
3. *Rubrics*: Several rubrics were created to evaluate free response visualization assessments (nonmultiple choice questions). Rubrics provide an instructor a method to evaluate student progress. We defined four levels: 1 = emerging, 2 = developing, 3 = proficient, and 4 = advanced. Level 3 was set as the expectation for most students at a given academic level, with Level 4 including content that would be contained in responses that show a student is performing at a higher level than expected.

4 | WHAT'S NEXT?

Despite the ubiquity of biomolecular representations in life sciences education, the instruction and assessment of biomolecular visual literacy is virtually nonexistent. Herein we describe workshops led by BioMolViz (BioMolViz.org) to build a community of practice that creates assessments targeting biomolecular visual literacy and BMV skills. We learned much as our workshops evolved over the course of two years. We share many of these lessons (Supporting Information S2), as they may be instructive to other members of the scientific community who are designing workshops on various topics. We also demonstrate how SNA can be used to capture the evolution of our community of practice. The expansion of our community included the intentional building of capacity for broader inclusion. Guided by outcomes from these workshops, we now plan to expand visualization instruction to focus on diverse models, to address challenges in group work to focus on visualization-focused assessments, and to grant open access to the assessment products of our workshops for the broader life sciences education community. This project will continue with a Research Coordination Networks in Undergraduate Biology Education (RCN-UBE) grant from the National Science Foundation.

As we continue to grow our network, we invite all to join our community of practice. Individuals who are interested in becoming more involved can connect with our community through our website at BioMolViz.org.

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CONFLICT OF INTEREST

All co-authors report no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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