Received: 4 May 2020 | Revised: 15 November 2020 | Accepted: 14 December 2020

DOI: 10.1002/bmb.21488

ARTICLE

Biochemistry and Molecular Biology Education WILEY

Data-rich textbook figures promote core competencies: Comparison of two textbooks

Brooks Finby[1] | **Laurie J. Heyer**[2] | **A. Malcolm Campbell**[1]

[1]Department of Biology, Davidson College, Davidson, North Carolina, USA

[2]Department of Mathematics and Computer Science, Davidson College, Davidson, North Carolina, USA

Correspondence
A. M. Campbell, Department of Biology, Davidson College, Davidson, NC.

Abstract

Many molecular biology and biochemistry instructors have altered their classroom behavior in favor of evidence-based, active learning instructional strategies. Overwhelming evidence confirms that lecture-only classrooms are detrimental to student learning outcomes, but we know less about the impact textbooks have on students outside the classroom. Two influential projects, the AP Biology redesign and *Vision and Change*, called for extensive restructuring of course content and hoped that textbooks would be restructured accordingly. This study evaluated all figures and tables from two introductory biology textbooks to quantify how well they implement recommendations from *Vision and Change* and AP Biology redesign. We documented significant differences among figures and tables when looking for experimental data, questions for students to answer, and quantitative interpretation. Using think-aloud interviews, we interrogated whether students engage differently with figures from the two textbooks. When figures provided take-home messages, students relied on written text rather than analyzing the graphical information for their understanding. Students frequently employed words from summaries within the figures to construct "inflated explanations" that mimicked comprehension.

KEYWORDS

core competencies, introductory biology, quantitative reasoning, scientific process, textbook

1 | INTRODUCTION

For decades, education reformers have called for changes to the way biology is taught, especially at the introductory level (Study Group, 1990; Narum, 1991; Tobias, 1992; Narum, 1998; Uno, 1999; Council, 2003). Their calls were not to change for change's sake, but to improve student-learning outcomes. Justification for these changes include training a science-literate workforce,[1] a more informed voting public that supports basic research[2] and increased diversity of students who pursue STEM majors.[3,4] The AP Biology redesign and the report *Vision and Change* explicitly called for a focus on two aspects of learning biology.[5,6] First, students should not be overwhelmed or distracted by endless lists of glossary words and repetitive examples of similar concepts. Instead, these two faculty-led biology projects, which developed independently at about the same time, called for an emphasis on big ideas (AP Biology) or core concepts (*Vision and Change*). Furthermore, both projects wanted students to learn scientific practices (AP Biology) or core competencies (*Vision and Change*). Vision and Change outlined five core competencies because "a competency-based approach to undergraduate biology education focuses on demonstrating analytical, experimental, and technical skills as measurable outcomes of student learning. Biology literacy is defined primarily in terms of acquired competencies, demonstrated within the context of fundamental biology concepts".[6] Because all molecular biology and biochemistry upper level courses require introductory courses as prerequisites, reform at the lower level courses will affect student performance in advanced courses. This study compared two textbooks to determine how well they address core competencies.

Two of the five core competencies are particularly relevant in this study: ability to apply the process of science and ability to use quantitative reasoning. Applying the process of science was justified because biology is an evidence-based discipline.[6] Examples for the process of science included hypothesis testing, evaluation of experimental evidence, and developing problem-solving strategies. The justification for quantitative reasoning was based on biology's reliance on quantitative analysis and mathematical reasoning. Students who develop quantitative reasoning should be able to interpret graphs, apply statistical methods to diverse data and analyze large datasets.[6] In 2015, Couch et al. developed a taxonomy of 15 pedagogical goals and 37 observable supporting practices.[7] They characterized three science practices relevant to the core competencies of quantitative reasoning and the process of science.

1. Students use science process skills when they: identify, construct or evaluate hypotheses and make predictions based on their hypotheses; design and evaluate experimental strategies; and analyze data using appropriate statistical methods.
2. Students synthesize experimental results when they formulate conceptual models based on data; reconcile conflicting pieces of data; and develop arguments based on experimental data.
3. Students engage in formal scientific discourse when they read and evaluate scientific literature, including peer-reviewed publications.

About a decade before Vision and Change was published, a new field of scholarship arose, called discipline-based education research (DBER[8]). To support these scholars, several new journals were launched as venues for classroom practitioners and DBER scholars to exchange ideas that would infuse classrooms with evidenced-based instructional methods.[9–17] A growing number of molecular biology and biochemistry faculty employ evidence-based pedagogical approaches called active learning. Included in these approaches are clicker questions,[18,19] think-pair-share,[20] flipped classes[21,22] and problem-based learning.[23] All of these pedagogical approaches are designed to change what happens in the classroom when instructors and students are together during class time. However, few DBER scholars or classroom practitioners have addressed active learning when students are reading a textbook on their own time.[24] Schornborn et al. showed that traditional biochemistry textbook figures negatively affect student learning.[25] Conversely, Walton showed that out-of-class reading assignments of real experimental results improved data analysis skills.[26] Similarly, a 2019 study showed that biochemistry experts use experimental evidence when explaining topics but biochemistry textbooks lack data to support student understanding[27] Students using one of the textbooks evaluated in this study, *Integrating Concepts in Biology* (ICB), also improved their competencies in the process of science and quantitative reasoning compared to students using a traditional textbook.[28] Schwartz et al. sampled over 8000 students from STEM courses at 55 colleges and universities.[29] They found that high school students who spent at least 1 month on at least one major topic earned higher grades in college science than students who reported no in-depth instruction. High school students who experienced breadth over depth in biology did significantly worse in college biology courses. Students in this study were matched for socioeconomic variables, English language fluency, mathematics proficiency, and rigor of their preparatory high school science courses. Schwartz et al. demonstrated the long-term benefits of adhering to Vision and Change recommendations of core concepts and competencies, summarized by the expression "less is more".[29]

Perhaps the most common active learning approach that focuses on student learning outside the classroom is the flipped class.[21,22] Bowles described a series of interventions that prepared students for classroom engagement to enhance their understanding.[30] A common implementation of the flipped classroom requires the instructor to record summary presentations for the students to watch before coming to class so that class time can be spent applying the new content while together in the classroom.[31] In biology, video and audio presentations are typically based on traditional textbooks that contain summary diagrams that tell students what they should know, and more new vocabulary words than first-year foreign language courses.[33]

In a traditional textbook, experimental results are rarely presented to students in their published format, and students infrequently apply the math they have been required to learn.[34] Duncan et al. surveyed six introductory biology textbooks to quantify the process of science core competency as represented by figures in each book.[36] They found that less than 5% of the hundreds of figures per book incorporated real experimental data. Of these six textbooks, only the one authored by Scott Freeman et al.[37] incorporated all the components investigators used to define the process of science. Duncan et al. called for textbook authors to increase substantially the number of figures that included experimental data and the process of science.[36] This study evaluated how well two textbooks achieved Duncan's recommendation.

Unfortunately, DBER scholars have paid less attention to the role of textbooks in student learning than the role of instructors in the classroom. Of the available research on textbooks, most of the findings indicate that textbooks are irrelevant to students.[32–40] A recent study compared open access textbooks to conventional textbooks to determine if one book type was better than the other.[41] The investigators found no significant differences in student outcomes. Faculty using traditional paper textbooks felt their books were superior to open textbooks, but students felt the two book types were equivalent. Ninety percent of faculty who chose open textbooks did so primarily for price and not quality, whereas 57% of faculty using non-open textbooks did so primarily because they felt students would learn the material better. Nevertheless, 85% of all faculty expected their students to read the textbook regularly, but only 29% of the students indicated they actually read their books.[41]

Given the significance of the Vision and Change report,[6] it might be surprising to learn that the report only mentioned the word "textbook" five times, one of which offers a vague recommendation (Table S1). "Clearly, more is needed than simply updating and modernizing the content and approach of textbooks." In 2002, Bowen and Roth analyzed the impact on student learning when figures (inscriptions) were modified for students.[42] The investigators found that even content experts found many of the modified educational versions of figures uninterpretable. Furthermore, they found that students garnered most of their understanding of figures from the main text and figure legends.[42] College textbooks, they reported, provide students with the take-home message in the legends and captions making the images superfluous. The pair concluded "Using [experimental data] to construct scientific claims is an important component of curriculum reforms".[42] The following year, Pozzer and Roth concluded that textbooks fail to apply consistent structural elements of research figures and the impact of these inconsistencies warranted further research.[43] To analyze visual literacy in textbooks, Rybarczyk documented that introductory biology textbooks had significantly fewer figures containing real experimental data.[44] Furthermore, only half of introductory biology textbook figures that described experimental methods actually represented experimental data. Additionally, Offerdahl et al. developed a taxonomy of visual representations in textbooks.[45] They questioned the authenticity of the tasks students are asked to perform in their textbooks, noting, "If students fail to develop fluency in introductory courses, they probably won't be able to integrate that knowledge in upper level courses." Collectively, these publications motivated this study's comparison of figures and tables in ICB and a traditional textbook.

Three 2019 publications offered more detailed analyses of textbook figures. Kjelvik and Schultheis analyzed why students maximize learning gains when they work with authentic data to improve their core competencies of the process of science and quantitative reasoning.[46] They agreed with Bowen and Roth[42] that students benefit from accurately reproduced "messy" figures taken from published research articles which is consistent with a study of biochemistry students. Kjelvik and Schultheis acknowledged the dearth of readily available messy figures in student-friendly scaffolding.[46] However, when novice college students are given authentic research figures in the absence of educational scaffolding, they do not spend sufficient time looking at critical aspects of the figure, despite verbalizing that they did.[47] Using eye-tracking technology, Harsh et al. found that novice students and content experts look at and spend time on different aspects of data-rich figures.[47] A different study used think-aloud interviews of students in an active-learning classroom and documented that individual students engaged very differently with the same in-class activities.[48] The authors noted that grades offered limited understanding of student perceptions about their learning: "Grades are a proxy and not an ultimate indicator of successful learning." Findings from these in-depth analyses of how students engage with figures led to this study's comparison of figures and tables as presented in two textbooks.

One author (AMC) was involved in phase I of the AP Biology redesign project in 2006–2007. By the end of that year, it became clear that existing textbooks were part of the impediment to meaningful student learning. After recusing himself from further involvement in the AP redesign, he and two other faculty from Davidson College wrote ICB[49] that could be used for AP biology and college-level introductory biology for STEM majors.[2,5] From the outset, ICB leveraged the finding that students learn best when they construct their own knowledge and when they employ the process of science as they constructed their understanding.[42,50] A pedagogical device in ICB called "integrating questions" asks students to analyze and interpret published data. Thus, students practice the core competencies of the scientific process and quantitative analysis while they learn core concepts.[28,52] However, one limitation is that ICB is a commercial book and thus is not free to all students which will limit access for many students around the world. To reduce this limitation, ICB's publisher, Trunity, offers reduced pricing for high schools and institutions outside the United States, and scholarship programs for students with demonstrated need.

The foundation for this study was the hypothesis that textbooks with more authentic figures and tables (inscriptions) would enhance the core competencies of scientific process and quantitative analysis[38–48] which would affect upper level courses such as molecular biology and biochemistry. One possible way to make such comparisons would be to sample a few equivalent chapters from many textbooks. However, the chapters of ICB are organized in a unique way. Each chapter is organized around 1 core concept (out of 5) and 1 size scale (out of 5) so an equivalent chapter comparison was not possible. Therefore, we evaluated every figure and table from two textbooks to see if their content was significantly different.

During the formative stage of this research project, we informally polled college biology faculty to name the traditional textbook they thought had the greatest emphasis on experimental data. Although the opinions were not unanimous, many faculty thought *Biological Sciences* by Scott Freeman et al.[37] had the most data out of all the traditional textbooks, which was consistent with literature findings.[36,45] Therefore, we compared ICB (summer 2016 edition[49]; with the 6th edition of *Biological Sciences*.[37] We evaluated a total of 1598 figures and 226 tables and rated them for three criteria.

1. Does the figure or table contain experimental data?
2. Are there one or more specific questions for students to answer that require the figures or tables for the answers?
3. Does the figure or table provide students with the take-home message (summary), or must students analyze the figure or table in order to extract the main points (interpretive)?

We confirmed that ICB figures and table contain substantially more data, require more interpretation and are more connected to questions that facilitate students constructing their own knowledge. We and others have already shown improved student outcomes when students use ICB.[28,53,54] We also showed that one semester was insufficient for data interpretation skills to persist 6 months later.[28]

After quantifying differences for figures and tables, we asked a follow up question: Do students engage differently with figures from the two textbooks? We conducted think-aloud interviews with eight incoming first year college students as they engaged with five paired images from the two books that addressed commonly taught concepts in molecular biology and biochemistry courses: antibody structure and function; evolutionary origins of mitochondria and chloroplasts; hemoglobin function; neuronal function; and carbon fixation. We found students used "inflated explanations" to describe the figures which provide take-home messages and lack authentic data. Inflated explanations contain words that make it sound like students understand the content depicted when they mimic words found in the figure legends and labels. By contrast, students used "individualized explanations" when describing figures that contained authentic data but lack take-home messages. Because ICB figures contain more data and rarely provide take-home messages, first-year students in this study used more individualized explanations for ICB figures and more inflated explanations for Freeman figures. Thus, this sample of students engaged differently with figures that lack take-home messages but contain authentic data. In short, a textbook can promote core competencies through data-rich figures and tables that omit take-home messages.

2 | METHODS

2.1 | Figure and table analysis

We classified figures and tables in three categories, each with two mutually exclusive choices: (a) summary or interpretative; (b) question or no question; (c) data or no data. We developed the following definitions for these choices. A figure or table is called *summary* if it requires no analysis; it only summarizes the text or supplements it with a written take-home message. Conversely, a figure or table is *interpretative* if students must analyze its information to extract meaning; the take-home message is not provided for the student. In order for a figure or table to be associated with a question, the visual element must require information in the element to answer an explicit question for students, rather than relying on the written text alone. If a question can be answered by the text alone and does not require information from the figure or table, the element was classified as not having a question. For a figure or table to be scored as containing data, it must present results from a real experiment, rather than just a theoretical or hypothetical example. We applied these criteria to two textbooks: ICB (summer 2016 edition)[49] and the 6th edition of Biological Sciences by Freeman et al. (BSF).[37]

2.2 | External evaluator survey

We validated our figure and table classifications by asking faculty who regularly teach biology to undergraduates to score a subset of the figures and tables. We submitted an email call for participation via two online communities of undergraduate biology educators: SABER, Society for the Advancement of Biology Education Research; and GCAT—the Genome Consortium for Active Teaching. Fifty faculty completed the survey and nine more faculty answered some but not all of the questions. We used the results from all 59 full and partial submissions (referred to as external evaluators) to validate our scores.

The online Qualtrics survey contained two parts. The first part was a training set of five paired and curated examples that explained the three mutually exclusive categories of the figures or tables. The five pairs consisted of one example from each book. The second part was the experimental set of 30 randomly selected figures, 15 from each textbook, and 10 randomly selected tables, 5 from each textbook. The figures and tables were randomly selected via a random number generator assigned to corresponding figures or tables. The order of the figures and tables in the survey was determined by random assignment. External evaluators could click on any combination of five options: Experimental Data; Interpretive Figure; Summary Figure; Figure with Question; None of these apply.

Prior to the training set, we provided external evaluators with the goals of our research and instructions that included definitions of the rating terms. The training set gave evaluators an understanding of the online rating process for all 10 examples in the training set. The experimental tables and figures were presented in groups of five per screen. At the top of each screen were definitions of the rating terms as convenient references. The median time spent on the survey by the 59 external evaluators was 26.2 min.

2.3 | Data analysis and visualization

We used the R software package to analyze survey responses from the external evaluators and build the graphs. The open source code is available in the supplemental material for others to adopt and adapt.

2.4 | Think-aloud interviews

Incoming first year Biology majors from the University of Georgia were recruited via email from their assigned advisors for voluntary think-aloud interviews[48,55] 1 week before the start of their fall 2019 semester. Twelve students scheduled sessions, but only eight students (4 male and 4 female) showed up. Each participating student was paid $25 for their video-recorded interview, which lasted approximately 30 minutes. Students were given one non-biology figure as practice of the think-aloud method. Paired experimental figures were selected from ICB and BSF that addressed the topics of:

- primary and secondary antibody response (ICB figure 5.9 and BSF figure 48.17);
- evolution of organelles using evolutionary trees (ICB figure 6.18 and BSF figure 27.9);
- hemoglobin response to oxygen and pH changes (ICB figure 13.3 and BSF figure 42.17);
- threshold activation for action potentials in neurons (ICB figure 9.5 and BSF figure 43.4);
- carbon fixation in photosynthesis (ICB figure 11.13 and BSF figure 10.18).

Which image appeared first among the pairs was randomly determined prior to the interviews. Interviews were recorded, transcribed and coded using AtlasTI. AMC conducted all the interviews over a two-day period and used inductive coding to evaluate all eight interviews. LJH independently used deductive coding to confirm the original coding. Any disagreements were discussed until a consensus was reached. Of the 32 codes developed, the major insight into student engagement centered on two codes: “inflated explanation” and “individualized explanation.” Individualized explanation was meant the student describes what is going on in the figure using his or her own words based on interpreting the image. Inflated explanation was defined as using the right words, but the student's understanding was accompanied by an admission of not understanding, marked by a code of “no understanding.” Human subjects institutional review board approval for exemption #2019-050 was granted by Davidson College prior to the interviews.

3 | RESULTS

For every figure and table in both books, we asked three questions: (a) Does the item contain experimental data? (b) Is the item associated with a question? (c) Does the item require interpretation or is it summary in nature? To answer these three questions, we needed to establish working definitions (Table 1). To qualify as data, an item must contain real experimental results that had been published. Items did not have to look exactly like the original published figure, but they could not be hypothetical representations of concepts in the absence of experimentation by investigators. Example of figures lacking data would be a photograph of an organism with its anatomical parts labeled, or illustrations that presented an overview of an experimental method. For an item to be

TABLE 1 Working definitions for evaluating figures and tables

Data	Must contain results from a real experiment, not a hypothetical or theoretical one; could not be an illustration or photograph mainly for visual interest.
Question	Students must use information in the item to answer a question or supply missing information; answer not presented in the text.
Interpretive	Students must analyze the information in the item to extract meaning; take-home points were not provided for the students with the item.
Summary	The item requires no analysis; it merely summarizes or supplements the text; take-home point provided for students within the item.

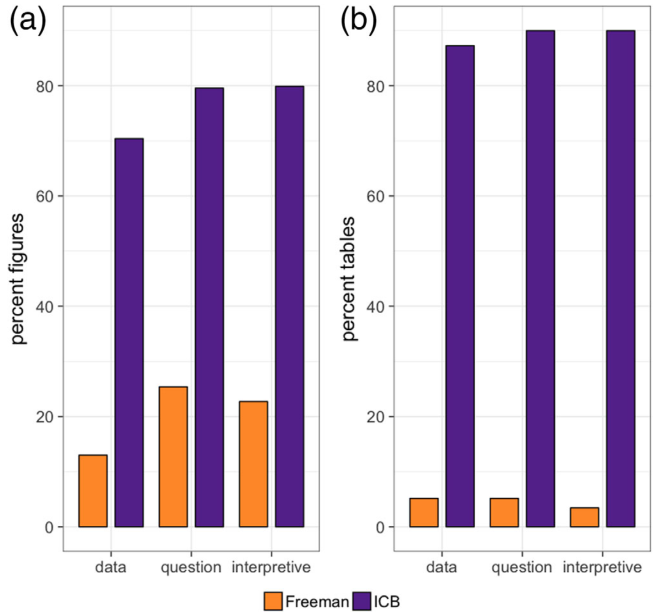

FIGURE 1 Comparison of figures and tables between Freeman and ICB. We scored every figure (a) and table (b) for presence of experimental data, whether a question was associated with the figure or table, and whether the figure required interpretation. Freeman had a total of 976 figures and 116 tables; ICB contained 622 figures and 110 tables. ICB, integrating concepts in biology

associated with a question, the text either included a question that directly referred to a figure or table, or contained a statement that asked students to interact with the item, such as "Fill in the missing information for this table." Summary items provided the take-home message or illustrated information such as the biconcave shape of red blood cells. Conversely, interpretive items required students to interpret results and formulate a conclusion based on the data within the item itself. For example, in a graph showing the induction of light production by *V. fisheri*, students had to interpret the data to determine when luciferase enzyme production began.

The Biological Sciences textbook by Freeman (BSF) is composed of 54 chapters that contain a total of 976 figures and 116 tables. ICB is composed of 30 chapters with a total of 622 figures and 110 tables. We only counted items within the text of numbered chapters and did not include items that contributed to end of chapter review materials. We did not count videos embedded within ICB, nor did we consider Chapter 0 of ICB, despite it containing figures and questions that introduced students to the benefits of active learning and statistical analysis.

For every item, we determined whether it contained data, if a question was clearly associated with the item, and whether it was interpretive or summary (Figure 1). In BSF, 13% of the figures and 5% of the tables contained data produced by experiments. For ICB, 70% of the figures and 87% of the tables contained data reproduced from published experimental results. The data difference for tables is more pronounced than figures in part because ICB frequently asks students to perform mathematical functions on data from published experimental results presented in tables. The highest score for BSF was for figures associated with questions (25%). BSF uses reflective questions within the chapter as a mechanism to highlight main concepts and prompt students to consult figures and tables. The number of tables in BSF associated with questions was only 5%, the same value as tables containing data. ICB received higher scores for both tables and figures associated with questions, with 80% of figures and 90% of the tables. ICB uses Integrating Questions that occur throughout each section but additional Review Questions at the end of each section were not included in this analysis.

Based on the definitions provided in Table 1, all items either had to be summary or interpretive. Therefore, it was not surprising that the percentage of figures and tables that were interpretive correlated with the percentage of items that were associated with questions. For example, if students were asked a question about a figure, it was usually interpretive (contained information that had not been summarized for students). Similarly, photographs of organisms did not require interpretation and rarely had questions asked about them. In ICB, 80% of its figures and 90% of its tables were interpretive. Figures in BSF were interpretive 23% of the time, and tables were interpretive 3% of the time. Many items in BSF provided the take-home message for students and therefore did not require interpretation. The abundance of take-home messages became relevant during the think-aloud interviews described below.

After we evaluated all 1824 visual elements from both books, we compared our ratings with those of other biology faculty who frequently teach undergraduates (external evaluators). We provided these external evaluators with the working definitions for the four terms as shown in Table 1. Each evaluator began with a training set of visual elements to clarify the mutually exclusive categories. For each pair of training-set items, we indicated how we defined each visual element and why we scored them accordingly. By connecting specific items with defined categories, we helped evaluators adjust to the online interface and measured rater compliance, which was not 100% (Figure 2). The vast majority of evaluators successfully rated each paired training item as instructed. Two or three evaluators failed to comply as instructed in the training set perhaps because they disagreed with our definitions, or because they made a mistake by clicking on the wrong selection. We did not exclude any external evaluators even if their compliance was low on the training set.

When evaluators rated the 30 randomly selected figures (15 from each book), on average they agreed with our ratings between 72% (interpretive figure) and 90% (figure with data and associated question). Evaluators rated 10 randomly selected tables (5 from each book) and agreed with our ratings 90% of the time for data and type, and 100% of the time for tables associated with questions. In every category of Figure 2, there are a small number of people who disagreed with our ratings, which could be true disagreement or confusion due to the Qualtrics interface. Despite the few external evaluators who rated items differently than most others, the high degree of rating agreement validated that the differences between the two books in Figure 1 would be detected by most faculty. Therefore, there is a very large difference between ICB and BSF textbooks with regards to student access to experimental data, questions that ask students to engage with the items, and whether the items are summary or interpretive.

We asked external evaluators to score only 10 tables, five from each book, because there are fewer tables than figures in both books. Overall, the external evaluators agreed with our assessments of the tables to a higher degree than the figures, perhaps because tables are more clearly either experimental data or not (Figure 3).

3.1 | Think-aloud interviews

Having established that ICB figures and tables are substantially different from those in BSF, we wanted to

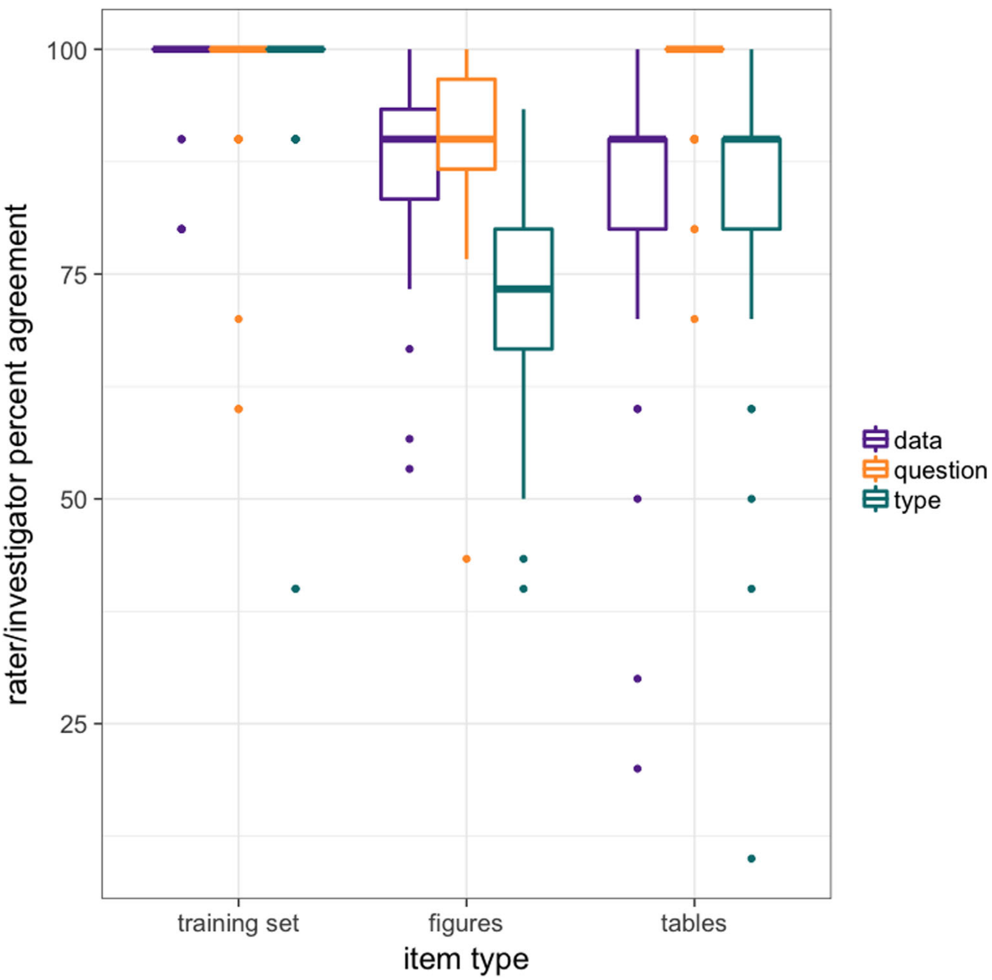

FIGURE 2 Item rating agreement with 50 external evaluators who rated all 45 items (5 training and 40 experimental). Evaluators were provided with 5 paired examples (training set) to define terms and to instruct them how to rate these items for data, question and integrative versus summary. Evaluators independently rated 30 figures and 10 tables, randomly selected and presented. Agreement for figures and tables are considered separately for the three categories as shown in Figure 1: Data; question; type of item (interpretive vs. summary). Box plots show mean percent agreement (bar), 25%–75% percent rating agreement range (box), 95% rating agreement range (whiskers) and any additional raters with lower percent rating agreement (dots). The four horizontal bars at 100% represent all values other than outliers

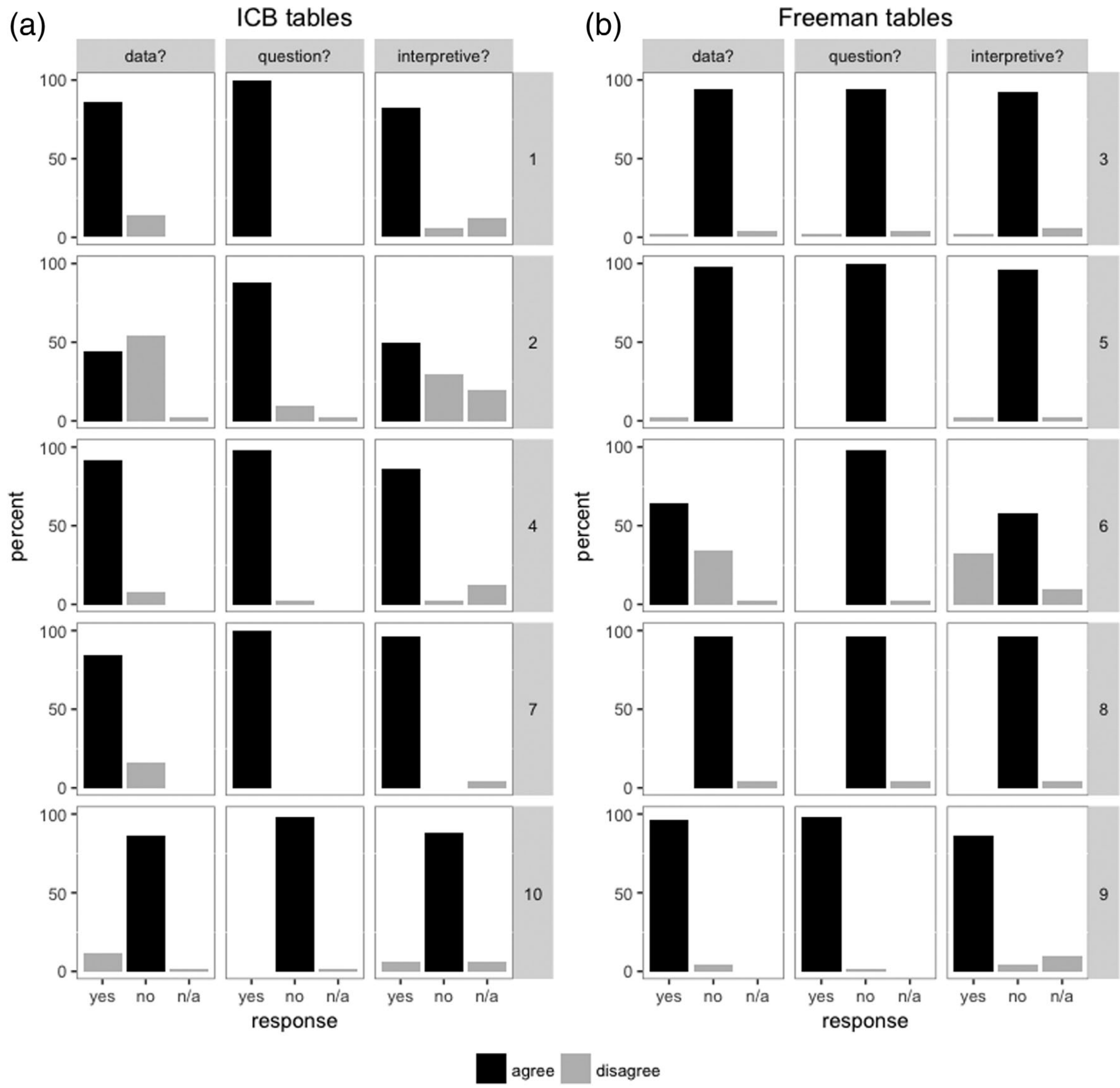

FIGURE 3 Percent agreement with external evaluators on table ratings. Black bars indicate the percent agreement for the 5 ICB tables (a) and the 5 Freeman table (b). Gray bars indicate the percent disagreement. The numbers on the right side indicate the order in which the 10 tables were presented to outside evaluators. Each table was scored for data (left column), association with a question (middle column), and table type of summary or interpretive (right column). The summation of all ratings for one table in one column equals 100%. ICB, integrating concepts in biology

know how students engaged in the two different types of figures. While conducting the think-aloud interviews, it became apparent that students often restated phrases taken directly from figure legends or labels within figures.

- *I appreciated the labels on the physical graph for the secondary immune response. It led to my conclusion quicker and assisted in making the conclusion…. Because this image looked complex at surface level, I referred to the caption title mostly*. (Student 7)
- *I found myself searching for the labels in the beginning, and then I just had to recall what I had read, and read it again, to make sure I knew*. (Student 7)
- *So the text is providing a lot more help as opposed to the actual graph does*. (Student 11)
- *Also, the two different labels of what happened after 5 s and then 60 seconds, really show what happened; more compounds are produced. Then the conclusion just sums it up*. (Student 9)
- *I always go back to the title, 'Incorporation of radioactive carbon into organic molecules.' Okay, 'algae cells produce increasingly more complex organic molecules with longer exposure.' Okay, that's what they wanted me to get*. (Student 8)
- *I like that it gives me the response. It tells me what is. It kind of just spoon-feeds when the [antibody] response is larger and when the response is faster*. (Student 8)

- *I like the labeling. And then on this one even just tells you exactly what it wants you to know as it's a faster and larger [antibody] response.* (Student 3)

Without the benefit of the quotes above, it would have been easy to accept spoken explanations of figures as correct and representing in-depth student understanding. However, students freely admitted they used text associated with figures to formulate their explanations despite not understanding the data. Their admission led to the code we called "inflated explanation" to describe times when students sounded convincing, but actually failed to understand the figure. The following quotes came from students working with figures from BSF:

- *I was confused on how oxygen concentration was different from fraction of oxygen saturation. I think I weaseled my way to an answer that made sense.* (Student 7)
- *I was a little bit confused … I just did not really see the significance of that [pointing to figure] or how that tied into the visual, and I was just trying to find some way to connect the two when in reality everything you needed was really in that first sentence…. you can derive a conclusion without looking at what's provided [in the figure].* (Student 11)
- *Okay. So I see 'primary initial endosymbiosis occurred here in the plants.' Then secondary endosymbiosis… It says the 'red algal, and green algal chloroplast were transferred to other protists….' These dotted lines hindered my ability. I was a little confused about those as well as the brackets, cause they did not have labels.* (Student 9)
- *I got tripped over what I was thinking sometimes, because I was saying stuff that I did not really know what I was saying, and then I'd go back and read it or just forget what I had said. Because sometimes when I'm talking I say things that I'm just reading it and speaking it, and then I'm like, 'Wait, what did I just say?'* (Student 3)

Conversely, when students engaged with figures from ICB that lacked take-home messages, they had to come up with their own wording that reflected their understanding or lack of understanding. Student figure descriptions that lacked verbiage from labels or legends were coded as "individualized explanation." It was common for students to mildly complain about the extra effort ICB figures required.

- *I can see, just from a glance, the graphs are not labeled by those different currents, so that draws me to look closer at the actual lines in the graphs and see if… Okay, so they are labeled, just not by numbers. They're labeled with the red, I guess, key at the top. You just have to look at and compare… I was thrown off of it by how they chose to label the graphs with insets as opposed to just saying, "This is when 10 millivolts are applied and this is when 20 millivolts are applied." I think that took a little more energy to decipher.* (Student 7)
- *And so this [legend] I read here definitely helped, telling me to make sure I know that the Y axis was different for these. That helped me figure it out. ICB legend said to note different axes.* (Student 5)
- *On this one, it was more confusing because I did not get it at first, because I've never seen anything like this, but what helped me, the y-axis, relative antibody concentration times 100, and the x-axis, just the days.* (Student 8)
- *I now get, after all this time, it's an evolutionary tree. I think that just clicked in my head when I said that.* (Student 8)

The underlined portions of these quotes reveal that the students were employing two core competencies defined by Vision & Change[6]: the process of science and quantitative reasoning. Specifically, these students employed the process of science when they evaluated experimental evidence and developing problem-solving strategies. The students also revealed quantitative reasoning when they interpreted graphs and used statistical measures to evaluate diverse data. It is worth noting that the interviewed students had never read either textbook and approached the figures out of context and yet they demonstrated differences in the use of core competencies. ICB promoted these skills whereas BSF did not.

We summarized inflated versus individualized explanations for all the students and each figure used in the think-aloud interviews (Figure 4). The color-coded patterns are easy to see in columns. Inflated explanations were much more common for BSF figures than for ICB figures. Conversely, students used individualized explanations for ICB figures more often than they did for BSF figures. Furthermore, all eight students (rows) applied inflated explanations for at least 4 of the 5 BSF figures. Six students used individualized explanations for at least 4 ICB figures. Students were not able to formulate an explanation 11 times, with 8 of these stemming from ICB figures. A lack of understanding is not surprising since students had not read the text and were only looking at figures for a few minutes.

Student 11 was unable to offer coherent explanations for 4 of the 10 figures, the most of any student. This student self-identified as a visual learner and verbalized the tension faculty face when choosing textbooks and presenting data. On one hand, we want our students to have

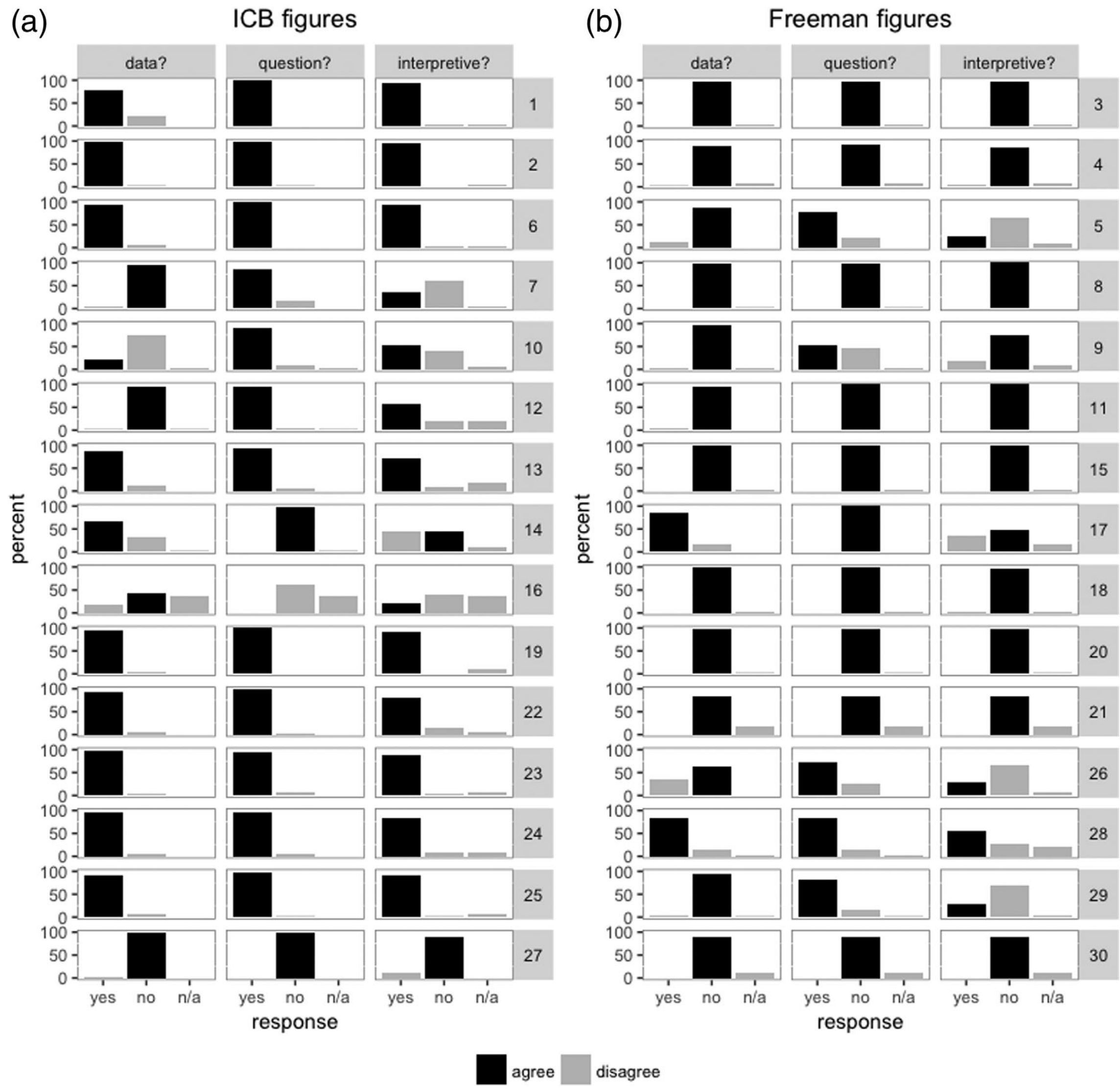

FIGURE 4 Percent agreement with external evaluators on figure ratings. Black bars indicate the percent agreement for the 15 ICB figures (a) and the 15 Freeman figures (b). Gray bars indicate the percent disagreement. The numbers on the right side indicate the order in which the 30 figures were presented to evaluators. Each figure was scored for data (left column), association with a question (middle column), and figure as summary or interpretive (right column). The summation of all ratings for one figure in one column equals 100%. ICB, integrating concepts in biology

a positive experience with textbooks and the figures they contain. "Maybe if it was just digital art or a cartoon-like reference I would be able to understand it, because it's just more clearly depicted and like I said, I'm just drawn to things like that." On the other hand, we want students to persist through the initial challenge of interpreting and analyzing data. We want them to engage with the data so they can develop the core competencies of scientific process and quantitative reasoning. Competencies cannot be memorized, and like any skill, competencies develop over time with repeated practice. This tension was summarized by student 11. "All right. So whenever I look at the graphs, I have trouble making sense of it. So I'm just going back to the text like I kind of did with the first or the second one... So the text is providing a lot more help as opposed to the actual graph does, because I don't know if [it's] just the way I'm wired or I don't know. But the text makes a whole lot of more sense.... But I'm just not drawn to the graphs. I'm just more so referencing the texts." Students have grown accustomed to figures that do not require them to employ the process of science or quantitative reasoning, so they prefer figures that provide take-home messages. Student 11 was frustrated and grew uncomfortable with the interview process. No teacher wants a student to feel uncomfortable when reading a textbook and yet we want them to develop core competencies. Given their prior exposure to textbook figures and tables, is it possible to help students develop core competencies in the absence of temporary frustration?

4 | DISCUSSION

Based on our analysis of all 1824 visual elements, we can confirm that ICB is significantly different from a traditional introductory biology textbook. ICB figures and tables contain more data, are associated with more questions, and require interpretation more often than in the BSF book (Figure 1). Our ratings were validated by 59 external evaluators who rated 30 figures and 10 tables randomly selected from each textbook (Figure 2). Our ratings did not align perfectly with the external evaluators, but the overall agreement was high (Figures 3 and 5).

The category with the greatest disagreement for the BSF figures was interpretive versus summary (see Figure 5b). Out of the four BSF figures where we disagreed the most with the evaluators, one disagreement (figure #9) might be due to an erroneous lighter font color and thus not noticing the question. However, three BSF figures (#5, #26 and #29) were rated as summary figures by the outside evaluators whereas we rated them higher as interpretive. If we were to use the evaluators' ratings instead of our own, BSF figures would drop from 27% interpretive (4 out of 15) to 7% interpretive (1 out of 15). We had rated 87% (13 out of 15) of ICB figures to be interpretive, but if we used the external evaluators' ratings instead, ICB figures would be between 73% and 80% interpretive because #14 was evenly split among the evaluators (see Figure 5a). Regardless the rating for #14, ICB figures contained more interpretation than BSF figures.

The external evaluators largely agreed with our ratings for the 10 tables. Only ICB table #2 was rated differently by a slight majority of the evaluators who felt the table lacked data as we defined the term. The nature of the information in this table, accidental death data collected from national statistics, makes it clear why a narrow majority of evaluators would rate the table as lacking experimental data. Despite this one disagreement, ICB tables contain significantly more data, are linked to more questions and are more interpretive than tables from BSF.

The first part this study quantified differences in textbook figures and tables that might affect student learning outcomes. Vision and Change called for improved core competencies for students,[6] but that call is not easy to answer. It took the authors of ICB 3 years to write the textbook (and another 4 years to publish it). Traditional textbooks are essentially unchanged as documented by the fact that each one has been published in multiple editions (Freeman 6th edition). By comparison, ICB was written de novo and with the benefit of AP Biology redesign plus *Vision and Change* recommendations..[5,6] Specifically, this work demonstrated that students employed the process of science and quantitative reasoning core competencies with tables and figures from ICB more than BSF.

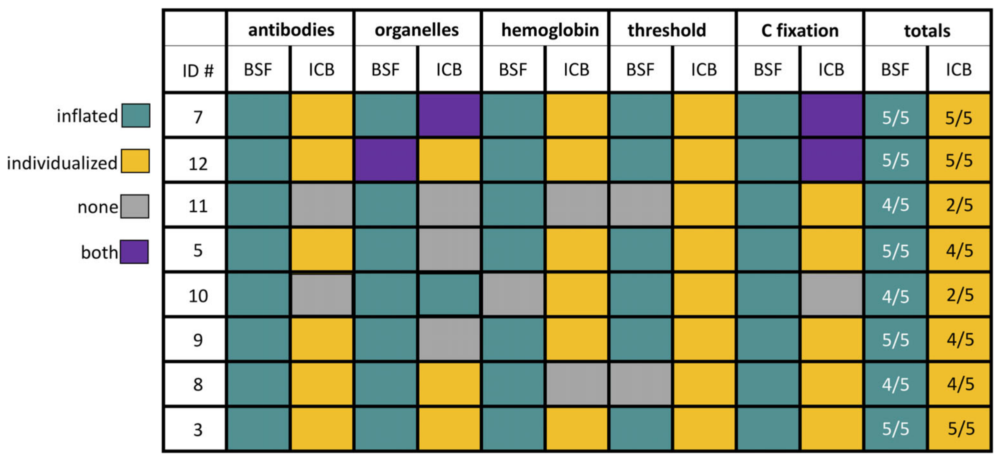

FIGURE 5 Think-aloud interview qualitative data summary. Coded interview summary from eight students (left column) for 10 paired figures (top row). Topics are provided with short captions and textbook source is abbreviated BSF (biological sciences by Freeman et al.) and ICB (integrated concepts in biology). Teal boxes show when each student used “inflated explanations” when describing a figure. Gold boxes indicate when students employed “individualized explanations” to describe figures. Purple boxes indicate when students blending inflated and individualized explanations. Gray boxes show when student were not able to understand figures sufficiently to offer meaningful explanations. The last BSF column tallies how many times each student used inflated explanations with BSF figures. The last IBC column tallies how often each student used individualized explanations for ICB figures. Purple boxes were added to inflated and individualized explanation tallies. Gray boxes were not included in either tally. ICB, integrating concepts in biology

Scott Freeman is a prominent DBER scholar, but he is no longer a participating author for the textbook that bears his name. In the seminal 2014 publication by Freeman et al., the authors conducted a meta-analysis of 225 published studies and concluded that active learning methods in STEM classrooms reduce failure rates regardless of the discipline or class size.[56] In their Discussion, the authors noted that if the study had been a clinical trial, it would have been halted for ethical reasons. Students in the comparison groups who did not benefit from active learning instruction methods suffered from lower grades and it would be unethical to continue lecturing to students. In short, Freeman compared lecture-based classes to medical malpractice where the practitioner was performing a method that the literature shows is less effective. Based on our findings, would Freeman and colleagues consider it educational malpractice to use a traditional textbook that does not promote core competencies?

We only compared ICB to one textbook which is a limitation of this study, but we see our project as part of a much larger effort to understand how textbooks affect student learning. However, Duncan et al. reported that BSF[37] was the only textbook in their study that incorporated all the components they used to define the process of science.[36] Our method for comparison was just one of many possible comparisons others might perform. We did not evaluate alternative textbooks with unique approaches, some of which are open access and thus free to students,[57,58] though others have shown open-access textbooks are very similar to traditional commercial textbooks.[41] Because we knew that many would object to ICB authors evaluating their own textbook, we used external evaluators and independent transcript coding to reduce bias that favored ICB. For the sake of limiting the time external evaluators had to spend on the survey (26 min on average), we did not ask them why they chose each rating which is a limitation of this study. Despite these shortcomings, we hope our textbook analysis will motivate DBER scholars to study textbooks and student behavior when they are not in the classroom. As noted in the Introduction, another limitation of this study centers on ICB being a commercial book and thus not free to all students. To reduce this limitation, the publisher offers special pricing discounts, and educators are encouraged to contact the publisher, Trunity, for custom pricing. Currently, the textbook is limited to English only, which will limit accessibility for many international students.

Think-aloud interviews uncovered an unexpected aspect of student engagement with textbook figures. Students frequently rely on text within legends or figure labels to verbalize what sounds like correct explanations of the figures. Instead, their shared thoughts illustrate what we coded as "inflated explanations." Inflated explanation is facilitated by figures that provide take-home message verbiage in their legends and/or labels (Figure 3). Our findings are consistent those of Bowen and Roth who concluded that exposing student to educationally modified figures was insufficient to generate core competencies.[42] Conversely, "messy" figures that contain authentic experimental data allow students to develop core competencies of science process and quantitative reasoning by practicing these skills at the same time they are learning core concepts.[46] Pozzer and Roth recommended further research to understand how students engage with textbook figures and what influence figures have on student learning.[43] As Offerdahl et al. warned, students will not be able to use visual literacy skills in upper level courses if they do not develop fluency during their introductory courses.[45] More recently, Jeffery et al. urged biochemistry instructors to provide their students with experimental data to support their understanding.[27] Although this study included a small number of student interviews, our findings are consistent with the reports of others and thus independently supported.

STEM students are best served when their early courses provide more depth and less breadth.[59,60] One way to enhance student learning outcomes is to emphasize the process of science and quantitative reasoning by providing inquiry or CURES laboratory experiences.[61] Ferrare analyzed STEM instructional practices for 71 introductory courses at six institutions and found four major categories of practices.[63] The most common practice for introductory biology courses was "slide shows" during which instructors present material from PowerPoint slides (70% of their time) mixed with real-time clicker questions (11% of their time). Ferrare reported that faculty who employ slide shows see themselves as facilitators of knowledge. He concluded that faculty connect the way they teach with the way they conceptualize the learning process, "regardless of whether that understanding has empirical merit." However, Bathgate et al. surveyed 584 STEM faculty who had been trained in evidence-based teaching and found that an instructor's perception of community support was the major determining factor for use of evidence-based teaching methods.[64] Are these two contemporary reports as contradictory as they seem? Could faculty incorporate their understanding of the learning process into evidence-based teaching methods if they were provided with sufficient support from a textbook that promotes core competencies?

Walton reported biology students improved their core competency of quantitative reasoning with the use of out-of-class reading assignments based on primary literature.[26] Wiles found biology students, especially women, felt more confident and preferred learning by analyzing authentic data figures (process of science) rather than lectures.[65] Hoffman et al. redesigned introductory biology with new modules for acquiring core competencies (process of science and quantitative reasoning) while learning core concepts.[66] Students are able to practice core competencies while learning core concepts.[7,67] Based on all these reports, it seems faculty have every reason to adopt these methods, yet resistance remains. Perhaps a 2019 physics DBER study helps us understand why some faculty might hesitate. Deslauriers et al. found that despite larger learning gains, physics students in active-learning courses felt like they learned less than their passive-learning peers felt.[68] Only by explicitly teaching students the benefits of active learning were students able to perceive their own learning, which can improve motivation and engagement, two key factors necessary for student learning.

One way to provide structural support so that more faculty adopt evidence-based teaching methods might be to provide them with a textbook that integrated core concepts and core competencies simultaneously.[69] The AP redesign as well as Vision and Change called for dramatic shifts to improve student learning.[5,6] The DBER community has focused largely on instructional practice when faculty and students are together. We know less about how textbooks influence student learning. As noted earlier, traditional biochemistry textbook figures harm student learning.[25] Perhaps textbooks that promote core competencies can provide a supportive environment that leads to different perceptions of the learning process.[63,64] Vision and Change outlined clear goals for instructional practices[6] but only mentioned textbooks five times (Table S1). If we want to engage students in meaningful ways that avoid inflated explanations, we must provide them with messy research figures with unaltered and authentic data that biochemistry experts use to explain their understanding.[27] ICB is only one of many possible implementations of a data-centric textbook that weaves the acquisition of core concepts and competencies. We have already shown that students retain core concepts longer and improve their core competencies when using ICB.[28] What we do not know is what additional textbook innovations can help students achieve the goals of Vision and Change. We hope that DBER scholars will continue to explore how students' out-of-class time spent with textbooks can maximize learning outcomes.

ACKNOWLEDGMENTS

We thank Erin Dolan for helping with the think-aloud interview process.

CONFLICT OF INTEREST

A. Malcolm Campbell and Laurie J. Heyer are the two senior authors of this manuscript and two of the three authors for the textbook Integrating Concepts in Biology (ICB). ICB is a commercial product sold by the publisher Trunity Global Learning Platform and the two senior authors of this manuscript receive royalty payments from the sale of ICB.

ORCID

A. Malcolm Campbell https://orcid.org/0000-0003-0877-4177

REFERENCES

1. President's Council of Advisors on Science and Technology. Report to the president, engage to excel: producing one million additional college graduates with degrees in science. Washington, DC: Technology Engineering and Mathematics; 2012.
2. Wood WB. Advanced high school biology in an era of rapid change: a summary of the biology panel report from the NRC Committee on programs for advanced study of mathematics and science in American high schools. Cell Biol Educ. 2002;1:123–7.
3. Jordan TC, Burnett SH, Carson S, Caruso SM, Clase K, DeJong R, et al. A broadly implementable research course in phage discovery and genomics for first-year undergraduate students. MBio. 2014;5:e01051–13.
4. Dewsbury B, Brame CJ. Inclusive teaching. CBE Life Sci Educ. 2019;18:fe2.
5. Wood WB. Revising the AP biology curriculum. Science. 2009; 325:1627–8.
6. AAAS. Vision and change: a call to action, final report; 2011. Accessed on 2 September 2015. Available at: http://visionandchange.org/finalreport/.
7. Couch BA, Brown TL, Schelpat TJ, Graham MJ, Knight JK. Scientific teaching: defining a taxonomy of observable practices. CBE Life Sci Educ. 2015;14:ar9.
8. Narum, Jeane. 1991. What Works: Building Natural Science Communities. Project Kaleidoscoe. Washington, DC. 100 pages.
9. Narum, Jeane. 1998. Project Kaleidoscope: Faculty for the 21st Century Handbook 1998. Project Kaleidoscoe. Washington, DC. 58 pages.
10. Offerdahl EG, Balser T, Dirks C, Miller K, Momsen JL, Montplaisir L, et al. Society for the advancement of biology education research (SABER). CBE Life Sci Educ. 2011;10:11–3.
11. Sundberg MD. Assessing student learning. Cell Biol Educ. 2002;1:11–5.
12. Lom B. Introducing The Journal of Undergraduate Neuroscience (JUNE) 2002. 1, p. E1.
13. Schwartz MS, Fischer KW. Building vs. borrowing: The challenge of actively constructing ideas. Lib Educ. 2003;89:22–9.
14. Moravec M, Williams A, Aguilar-Roca N, O'Dowd DK. Learn before lecture: a strategy that improves learning outcomes in a large introductory biology class. CBE Life Sci Educ. 2010;9: 473–81.
15. Dallimore EJ, Hertenstein JH, Platt MB. Impact of cold-calling on student voluntary participation. J Manag Educ. 2012; 1052562912446067.37:305–341.
16. Marbach-Ad G, McAdams KC, Benson S, Briken V, Cathcart L, Chase M et al. A model for using a concept inventory as a tool

for Students' assessment and faculty professional development. CBE Life Sci Educ. 2010;9:408–16.
17. Wood WB, Campbell AM, Tanner KD. Scientific Teaching Series; 2014. Accessed on 18 December 2018. Available at: https://www.ibiology.org/playlists/scientific-teaching-series/.
18. Smith MK, Trujillo C, Su TT. The benefits of using clickers in small-enrollment seminar-style biology courses. CBE Life Sci Educ. 2011;10:14–7.
19. Caldwell JE. Clickers in the large classroom: current research and best-practice tips. CBE Life Sci Educ. 2007;6:9–20.
20. Derting TL, Ebert-May D. Learner-centered inquiry in undergraduate biology: positive relationships with long-term student achievement. CBE Life Sci Educ. 2010;9:462–72.
21. Gross D, Pietri ES, Anderson G, Moyano-Camihort K, Graham MJ. Increased pre-class preparation underlies student outcome improvement in the flipped classroom. CBE Life Sci Educ. 2015;14:ar36.
22. Jensen JL, Kummer TA, Godoy PD d M. Improvements from a flipped classroom May simply be the fruits of active learning. CBE Life Sci Educ. 2015;14:ar5.
23. Allen DE, Duch BJ. Thinking toward solutions: Problem-based learning activities for general biology. Fort Worth, TX: Saunders College Publishing; 1998.
24. Hodges LC. Teaching undergraduate science: A guide to overcoming obstacles to student learning. Sterling, VA: Stylus Publishing, LLC; 2015.p. 41–62.
25. Schönborn KJ, Anderson TR, Grayson DJ. Student difficulties with the interpretation of a textbook diagram of immunoglobulin G (IgG). Biochem Mol Biol Educ. 2002;30:93–7.
26. Walton KLW. Improvement in student data analysis skills after out-of-class assignments[†]. J Microbiol Biol Educ. 2016;17: 466–8.
27. Jeffery KA, Pelaez NJ, Anderson TR. Using expert data to inform the use of research methods and representations to enhance biochemistry instruction and textbook design. Biochem Mol Biol Educ. 2019;47:513–31.
28. Barsoum MJ, Sellers PJ, Campbell AM, Heyer LJ, Paradise CJ. Implementing recommendations for introductory biology by writing a new textbook. CBE Life Sci Educ. 2013;12:106–16.
29. Schwartz MS, Sadler PM, Sonnert G, Tai RH. Depth versus breadth: how content coverage in high school science courses relates to later success in college science coursework. Sci Educ. 2009;93:798–826.
30. Bowles DJ. Active learning strategies…not for the birds! Int J Nurs Educ Scholarsh. 2006;3.
31. Tanner KD. Structure matters: twenty-one teaching strategies to promote student engagement and cultivate classroom equity. CBE Life Sci Educ. 2013;12:322–31.
32. Study Group. 1990. The Liberal Art of Science: Agenda for Action. American Association for the Advancement of Science. Washington, DC. 121 pages. ISBN: 0-87168-378-4.
33. Stevenson EN. An investigation of the vocabulary problem in college biology. J Educ Psychol. 1937;28:663–72.
34. Steen LA, editor. Math & Bio 2010: linking undergraduate disciplines. Washington, D.C: Mathematical Assoc. of America; 2005.
35. Tobias, Sheila. 1992. Revitalizing Undergraduate Science. The Research Corporation. 192 pages. ISBN: 0-9633504-1-2.
36. Duncan DB, Lubman A, Hoskins SG. Introductory biology textbooks under-represent scientific process. J Microbiol Biol Educ. 2011;12:143–51.
37. Freeman S, Allison LA, Black M, Podgorski G, Quillin K, Carmichael J et al. Biological Science. 6th ed. Boston: Pearson; 2017.
38. Downey MT. Pictures as teaching aids: using the pictures in history textbooks. Soc Educ. 1980;44:93–9.
39. Evans MA, HA Houghton, DM Willows et al., editors. A naturalistic inquiry into illustrations in instructional textbooks. Psychol. Illus. New York, NY: Springer US; 1987. p. 86–115.
40. Scott K, Morris A, Marais B. Medical student use of digital learning resources. Clin Teach. 2018;15:29–33.
41. Vander Waal Mills KE, Gucinski M, Vander Waal K. Implementation of open textbooks in community and technical college biology courses: the good, the bad, and the data. CBE Life Sci Educ. 2019;18:ar44.
42. Bowen GM, Roth W-M. Why students may not learn to interpret scientific inscriptions. Research in Science Education. 2002;32: 303–327.
43. Leivas Pozzer L, Roth W-M. Prevalence, function, and structure of photographs in high school biology textbooks. J Res Sci Teach. 2003;40:1089–114.
44. Rybarczyk B. Visual literacy in biology: a comparison of visual representations in textbooks and journal articles. Res Teach. 2011;41:9.
45. Offerdahl EG, Arneson JB, Byrne N. Lighten the load: scaffolding visual literacy in biochemistry and molecular biology. CBE Life Sci Educ. 2017;16:es1.
46. Kjelvik MK, Schultheis EH. Getting messy with authentic data: exploring the potential of using data from scientific research to support student data literacy. CBE Life Sci Educ. 2019;18:es2.
47. Harsh JA, Campillo M, Murray C, Myers C, Nguyen J, Maltese AV. "Seeing" data like an expert: an eye-tracking study using graphical data representations. CBE Life Sci Educ. 2019; 18:ar32.
48. Wiltbank LB, Williams KR, Marciniak L, Momsen JL. Contrasting cases: Students' experiences in an active-learning biology classroom. CBE Life Sci Educ. 2019;18:ar33.
49. Campbell AM, Heyer LJ, Paradise CJ. Integrating Concepts in Biology. Palo Alto, CA: Trunity; 2014. http://www.trunity.com/trubook-integrating-concepts-in-biology-by-campbell-heyer-paradise.html.
50. National Research Council. How people learn: brain, mind, experience, and school: expanded edition. Washington, DC: National Academies Press; 2000.
51. National Research Council. 2003. BIO2010: Transforming Undergraduate Education for Future Research Biologists. National Academies Press. Washington, DC. 208 pages. ISBN: 978-0-309-08535-9.
52. Luckie DB, Rivkin AM, Aubry JR, Marengo BJ, Creech LR, Sweeder RD. Verbal final exam in introductory biology yields gains in student content knowledge and longitudinal performance. CBE Life Sci Educ. 2013;12:515–29.
53. Harvey C, Eshleman K, Koo K, Smith KG, Paradise CJ, Campbell AM. Encouragement for faculty to implement vision and change. CBE Life Sci Educ. 2016;15:es7.
54. D. B. Luckie, et al. Integrating concepts in biology textbook increases learning: assessment triangulation using concept

inventory, card sorting, and mcat instruments, Followed by Longitudinal Tracking. (2017) 10.
55. Priede C, Farrall S. Comparing results from different styles of cognitive interviewing: 'verbal probing' vs. 'thinking aloud'. Int J Soc Res Methodol. 2011;14:271–87.
56. Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, et al. Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci U S A. 2014;111:8410–5.
57. Rye C, Wise R, Jurukovski V, DeSaix J, Choi J, Avissar Y et al. Biology. Houston, TX: OpenStax; 2016.
58. Klymkowsky MW, Cooper M. Biofundamentals. Boulder, CO: Virtual Laboratory; 2010.
59. Cooper MM, Posey LA, Underwood SM. Core ideas and topics: building up or drilling down? J Chem Educ. 2017;94:541–8.
60. Shaffer JF, Dang JV, Lee AK, Dacanay SJ, Alam U, Wong HY, et al. A familiar(ity) problem: assessing the impact of prerequisites and content familiarity on student learning. PLoS One. 2016;11:e0148051.
61. Luckie DB, Aubry JR, Marengo BJ, Rivkin AM, Foos LA, Maleszewski JJ. Less teaching, more learning: 10-yr study supports increasing student learning through less coverage and more inquiry. Adv Physiol Educ. 2012;36:325–35.
62. Uno, Gordon. 1999. Handbook on Teaching Undergraduate Science Courses: A Survival Training Manual. Saunders College Publishing. 159 pages. ISBN: 978-0-03-025926-5.
63. Ferrare JJ. A multi-institutional analysis of instructional beliefs and practices in gateway courses to the sciences. CBE Life Sci Educ. 2019;18:ar26.
64. Bathgate ME, Aragón OR, Cavanagh AJ, Frederick J, Graham MJ. Supports: a key factor in faculty implementation of evidence-based teaching. CBE Life Sci Educ. 2019;18:ar22.
65. Wiles AM. Figure analysis: a teaching technique to promote visual literacy and active learning: figure analysis: technique. Biochem Mol Biol Educ. 2016;44:336–44.
66. Hoffman K, Leupen S, Dowell K, Kephart K, Leips J. Development and assessment of modules to integrate quantitative skills in introductory biology courses. CBE Life Sci Educ. 2016;15:ar14.
67. Hester S, Buxner S, Elfring L, Nagy L. Integrating quantitative thinking into an introductory biology course improves Students' mathematical reasoning in biological contexts. CBE Life Sci Educ. 2014;13:54–64.
68. Deslauriers L, McCarty LS, Miller K, Callaghan K, Kestin G. Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. Proc Natl Acad Sci U S A. 2019;116:19251–7.
69. Feser J, Vasaly H, Herrera J. On the edge of mathematics and biology integration: improving quantitative skills in undergraduate biology education. CBE Life Sci Educ. 2013;12:124–8.

SUPPORTING INFORMATION

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

How to cite this article: Finby B, Heyer LJ, Malcolm Campbell A. Data-rich textbook figures promote core competencies: Comparison of two textbooks. *Biochem Mol Biol Educ*. 2021;49: 392–406. https://doi.org/10.1002/bmb.21488