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Just Figures: A Method to Introduce Students to Data Analysis One Figure at a Time †

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Quantitative data analysis skills are basic competencies students in a STEM field should master. In this article, we describe a classroom activity using isolated figures from papers as a simple exercise to practice data analysis skills. We call this approach Just Figures. With this technique, instructors find figures from primary papers that address key concepts related to several of their course learning objectives. These figures are assigned as homework prior to class discussion. In class, instructors teach the lesson and include a 10- to 20-minute discussion of the figures assigned. Frequent and repeated discussion of paper figures during class increased students' confidence in reading and analyzing data. The Just Figures approach also increased student accuracy when interpreting data. After six weeks of Just Figures practice, students scored, on average, three points higher on a 20-point data analysis assessment instrument than they had done before the Just Figures exercises. In addition, a course in which students consistently practiced Just Figures performed just as well on the data analysis assessment instrument and on a class exam dedicated to paper reading compared with courses where students practiced reading three entire papers. The Just Figures method is easy to implement and can effectively improve student data analysis skills in microbiology classrooms.

INTRODUCTION

A number of national initiatives have recently demanded that the educational and scientific community more effectively prepare students for their life after college both as scientists and as scientifically literate citizens. The American Association for the Advancement of Science and the National Science Foundation initiative published a report called *Vision and Change in Undergraduate Biology Education: A Call to Action* (1, 2), which describes the competencies and skills that students should master; these include the ability to understand and interpret data. The report also recommends making these core competencies part of any biological science curriculum that is reinforced throughout all undergraduate coursework.

Teaching students how to analyze figures from primary papers provides these students with transferable scientific communication and data analysis skills (3–10). However, the process of reading an entire journal article is often a daunting task for novice science readers (10) due to a preponderance of unfamiliar terminology, the inclusion of technical details, and often excessive complicated jargon, all of which are part of most primary scientific papers. Numerous techniques to improve students' abilities to read, comprehend, and analyze primary literature have been published. Examples include the journal club approach, the reading questions approach, the CREATE method, Figure Facts, Research Deconstruction, a paper-reading module and others (6–19). Most of these techniques require students to read a full research article and follow up with an in-class discussion to extract and deconstruct the data for students. However, not all of these methods are suitable for all classrooms. For example, journal clubs are very effective in small advanced class formats with ample discussion time, for students who can read papers independently, but are impractical in larger introductory courses (6, 7). The research deconstruction method requires one speaker presenting a research seminar followed by 10 teaching hours to deconstruct the speaker's research (8). Although the seminar deconstruction format is adaptable to a variety of subjects and scientific disciplines, the topic is narrowed down to the speaker's main research question and methods, which might limit its application. The CREATE (Consider, Read, Elucidate hypotheses, Analyze and interpret data, Think of the next Experiment) method specifically addresses information and jargon overload by withholding jargon-heavy text from the students (9–11). However, the CREATE method relies on discussion of several related papers (e.g., sequential papers), which may not be practical for courses where primary literature discussions are only one component of the course. A paper discussion method that uses guided paper discussions followed by a

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paper quiz was recently developed by some of the co-authors of this work (12). This method is practical for small and large courses; however, its application requires several classes or lectures dedicated to paper discussions and paper quiz.

Most of the published paper–reading exercises agree that students need structured guidelines, examples, and practice when learning to read entire papers (6–19). The Just Figures approach was designed to determine whether this can be accomplished using isolated figures rather than entire articles. Paper-reading guidelines that focus students' attention on figures rather than papers (Figure Facts) have been found to increase students' efforts to interpret data figures (18). Importantly, the Figure Facts approach also reduces the frustration often associated with reading papers (18). We propose taking this figure-focused approach further by simply assigning students isolated figures throughout each unit or course rather than assigning multiple papers. We present an exercise that uses isolated figures from papers for selected topics covered in lecture. Since basic background knowledge is essential for students to demonstrate critical thinking skills (20–24), choosing figures from papers directly related to course learning objectives provides the students the necessary background needed to facilitate data analysis. An added advantage to discussing one isolated figure is that the in-class time taken is reduced to a few minutes per class or week, depending on how often the method is used.

Intended audience

The data discussion exercises are intended for lecture courses (e.g., General Microbiology, Microbial Genetics, etc.) in which paper reading is not the main focus but is rather a way to apply data analysis skills. This exercise can also be implemented in research-based and laboratory courses as the first step in an incrementally challenging approach to have students read papers independently.

The exercise was tested in a Microbial Genetics course, an elective, face-to-face lecture course (Winter of 2016, Summer Session II 2016, and Winter of 2017, with enrollment of 14 to 26 students per quarter), 97% Senior (3% Junior), 49% females, 51% males. Winter 2018 was used as a control (enrollment of 14 students who were all seniors and 43% females), where the paper-reading method by Sato *et al.* (12) was used instead of Just Figures.

Learning time

The Just Figures method is a simple method that utilizes isolated figures from papers for each topic covered in lecture courses. Table 1 provides an outline of the planning required to incorporate this exercise into lecture courses. One of the largest time investments is finding one appropriate figure from a paper to discuss for each of several lessons. We recommend one figure a week for at least five to six weeks to provide sufficient practice for students. Support lectures or active learning sessions leading up to Just Figures should include basic background information related to the selected figure, including nomenclature, structures, mechanisms, and techniques. Some of this information can be added in the figure legend before the figure is assigned to the students (Appendix 3). Table 2 provides two examples of figures aligned to two common topics, transcription and horizontal gene transfer, taught in General Microbiology and Microbial Genetics courses. We provide additional examples and resources for finding good figures in Appendix 2.

The exercise requires about five minutes of added teaching time to discuss techniques or background information related to the figure. Students usually need 10 to 15 minutes to answer/discuss the general discussion questions listed in Table 2. Finally, three to five additional class minutes can be used to assign formative assessment questions as either a handout or personal response system (clicker) questions. We recommend providing the figure with information and legend before class, as part of a prelecture homework assignment. This way, class time can be spent answering the discussion questions rather than simply reading the figure. This is especially important for classes with short lecture periods (60 minutes or less). Instructors with longer lecture periods (60 to 90 minutes) can assign the selected figure as a handout (Appendix 3) in class.

The first time the students work on a data figure, it can take a substantial amount of class time, but this improves with practice and frequent use of the exercise. We recommend using the same general discussion questions for all assigned

TABLE 1.
Just Figures implementation outline.

Lesson Planning
Pre-planning
a. Design a lesson on the class/week topic using preferred method: for example, lecture, mini-lecture, recorded video, reading guide plus active discussion.
b. Select a figure directly aligned to the day's learning objectives. Allocate 5 to 20 minutes of class time for figure discussion.
c. Assign the figure as a class handout or pre-class reading homework.
d. Lecture slides and/or guided reading study guides should specifically address all content and jargon students might need to understand the assigned data figure.
During class
a. Faculty teach lesson in desired format.
b. Lead a class discussion (5 to 20 min) about the assigned figure.
Instructor-guided discussion questions for all data figures
a. Describe the experimental design (consider drawing outlines if time permits).
b. Describe the variables measured.
c. List all controls.
d. Write one sentence summarizing the main result(s).
e. Describe the main conclusion or take home of the figure.

figures. The similar questions used to frame every figure discussed in class enable students to more quickly and easily find the information requested, such as identifying control and experimental groups, reading the axes on a figure, key elements of experimental design, and the conclusions that can be drawn from the data presented. This reduces the amount of class time they spend on task. Importantly, this also makes our method more transferable to exercises students might encounter in other classes (e.g., advanced and/or laboratory courses). To keep students engaged, we recommend including a three- to four-question formative assessment using either clickers, for large classes, or handouts, in smaller classrooms. This formative assessment should ask questions about specific data sets or variable measurements shown in the assigned figure, assessing quantitative skills. Once students realize they will be asked about those details, they usually get quite detail-oriented when reading the figure. Data analysis skills can be measured by summative assessments, such as exams or quizzes, with questions about the assigned figures (Table 2 and Appendix 4). This exercise is suitable for lower- and upper-division courses. For lower-division courses, the amount of guidance and discussion about mechanism, controls, variables, and techniques associated with the figure may take significantly more class time.

TABLE 2.
Just Figures examples.

Lesson Examples with Assessments		
	Example 1	**Example 2**
Lesson topic[a]	Bacterial promoters/Transcription	Horizontal gene transfer (HGT)
Data figure selected[b]	Figure 2 of Ross *et al.* (25)	Figure 2 of Warnes *et al.* (26)
Figure-related content to include in the lesson (as lecture slides or guided reading)	Generalities of bacterial transcription: a. RNA polymerase function and subunits b. Description of bacterial promoter boxes c. The interactions between RNA polymerase and promoter	Generalities of HGT (conjugation in particular) a. CFU counting b. Antibiotic resistance and HGT *c.* *bla* genes and their function
Formative assessments focus on questions that assess whether students can read the figure variables and understand the experimental design	1. The high transcription levels observed in lanes 1/2 in gel 3 (far right) are mostly due to the action of the wild type RNA polymerase. (TRUE/FALSE) 2. The middle panel of this figure includes a mutant: a. Promoter b. RNA polymerase c. Ribosome d. DNA polymerase	1. CFU for cells inoculated in stainless steel coupons remained high in all three treatments during the duration of the experiment. (TRUE/FALSE) 2. How did the researchers determine the bacterial load on the inoculated steel fragments? a. Serial dilutions and agar plates b. qPCR c. Electron microscopy d. Metagenomics e. absorbance
Summative assessments (exams)[c] Plan on writing questions that assess whether students can use data to support arguments or hypotheses.	1. These data show that wild type and mutant enzymes are effective in transcribing those promoters lacking the UP element, though levels of transcription might be low. TRUE/FALSE. Explain your answer. Support your argument with data shown in the figure. 2. What would happen if the UP element was deleted from the promoter of gene X? a. Transcription rate would increase. b. Transcription rate would decrease. c. Translation rate would increase. d. Replication rate would increase.	1. The authors hypothesized that copper surfaces prevent horizontal gene transfer. What evidence does Figure 2 provide to support this hypothesis? Describe at least one result shown in the figure that supports the hypothesis. 2. The coupons described in this figure made of different metals were used to: a. Save money in the experimental design. b. Demonstrate all metals were equally effective. c. Differentiate between different metal types. d. Differentiate between different bacteria types.

[a] 1 to 2 lecture meetings.
[b] For a student handout with these figures, see Appendix 4
[c] Answers in Appendix 5

Prerequisite student knowledge

The exercise we propose is intended to be used to complement other methods used in lecture courses by putting data analysis into the context of fundamental course content. For example, in a class about bacterial transcription, the instructor can use a figure from an article that is directly aligned to promoter identification to discuss in class (Table 2). Students should be exposed to the scientific background needed to understand the selected figure during pre-exercise reading or prior class periods, as exemplified in Table 1. This is important to reduce the frustration associated with interpreting data (10, 18). It is important that the lesson plan address all nomenclature, mechanisms, and technical vocabulary mentioned in the selected figure. For Example 1 (Table 2), the lesson plan should describe promoter boxes, such as the UP element, and the subunits of the RNA polymerase, including all jargon (such as mutant names). When all jargon is addressed prior to discussion, students spend their in-class time focusing on what is important: the data. We also recommend rewriting the figure legend to make it easier to read (Appendix 3). For the first few (1 to 3) figures used in class, students might need extra help identifying variables and controls, so we recommend including some guidance in the figure handout or reading guide (Appendix 3). For figures dealing with complicated techniques that students might not be familiar with, instructors should include information regarding how the technique works. We also recommend outlining how the experiment was run. This is particularly useful if using figures from papers that include a graphic abstract, as the experimental design is often outlined in an accessible manner.

Learning objectives

At the end of a course using the Just Figures strategy for at least half of the semester or quarter, students will:

1. Show increased confidence in reading and analyzing data
2. Identify and analyze experimental variables, controls, and results presented in published data, figures, and tables
3. Evaluate and interpret data in primary literature

PROCEDURE

Materials

Table 1 describes the planning and teaching approach for this exercise, including examples. Resources to find relevant papers and figures are found in Appendix 2. Table 3 describes the alignment between learning objectives and assessments. Example of data analysis and paper quiz assessments are included in Appendices 6 and 7. Appendices 4 to 6 include examples of handouts and questions that instructors can use for this exercise.

TABLE 3.
Alignment between learning objectives and assessments.

Learning Objective	Assessment
Increase confidence at reading and analyzing data	Hoskins *et al.* (10)
Demonstrate the ability to read, evaluate, and interpret data presented in primary literature	Formative: handout/clicker questions (Table 2) Summative: exam questions (Table 2), data analysis quiz (Sato and Kadandale [unpublished, Appendix 7])
Evaluate and interpret data in primary literature	Data analysis quiz and paper quiz (Figs. 1 and 2) (12)

Student instructions

This exercise is an active data discussion exercise that students practice in class. Students prepare for class by answering reading guides or watching recorded lectures (flipped classroom). We recommend faculty assign the figure with information and legend ahead of time. Students should come to class prepared to discuss the figure. Students can be asked to come to class with some notes about the general discussion questions. Class time is spent learning the class/week topic, including background associated with the figure, and answering the general discussion questions. During or after this discussion, students will answer questions on a handout (or with clickers) about the figure. It is important that the figures discussed in class are included in summative assessments, such as quizzes and exams, to increase student buy-in during the formative assessments and in-class discussion. Examples of reading instructions, handouts, and questions are found in Appendices 4 and 5.

Faculty instructions

This Just Figures exercise can be used in lower- or upper-division courses. It provides a simplified method for students to practice data skills that does not require dedicating entire class days to reading and discussing papers. It is important to select figures that are relevant and fully aligned with the lesson's learning objectives. This motivates students to see the relevance of the topic and minimizes exposure to unknown topics or excessive jargon, both of which cause frustration (10, 18). This exercise is especially easy to apply in active classrooms that are fully or partially flipped, team-based learning, or a hybrid of active learning methods. In order to understand a given figure, students need to spend more time in deep reading of the lesson topic.

Finding appropriate articles and constructing a reading guide for students to use as they interpret a single figure will typically take faculty one to two hours per figure at first. This time generally decreases with repetition, as faculty find sources that are relevant to their course objectives and have developed a reading guide with similar questions for each figure. The exercise requires 10 to 20 minutes of class time to discuss the chosen figure. The first few times, students might use all 20 minutes (or more), but once they get into the habit of reading data figures, the required class time for this exercise tends to decrease to 10 minutes. Instructors should include the general discussion questions with the figure pre-class reading assignment and ask students to come to class with notes on them to discuss with their peers (see Appendix 3). We recommend using similar discussion questions for all assigned figures so students know what to look for when reading before class. In our experience, small group discussions followed by a large class discussion work very well. In course feedback, students particularly favored discussions in which experiment outlines were drawn on the board or provided as a graphic abstract of the experiment.

Suggestions for determining student learning

Table 3 summarizes the proposed alignment between exercise objectives and assessments. We assessed confidence and students' attitude toward primary literature using the CREATE survey published and validated by Hoskins *et al.* (10). In addition, we used a tool designed by Sato and Kadandale (unpublished, Appendix 7) to assess students' ability to read and analyze data. Both instruments were administered before (pre) and after (post) the intervention. To assess paper-reading skills, we used a "paper quiz," as described by Sato *et al.* (12). An example of a paper quiz can be found in Appendix 6.

In class, we recommend using three to four questions assessing quantitative skills as individual formative assessments. In our experience, questions about measurements, data sets, units, etc. are effective at modeling detail-oriented reading of each figure (Tables 1 and 2 and Appendix 4). Finally, we recommend including the figures discussed in exams and quizzes. The level of complexity of exam questions can be adjusted to course level and goals, ranging from questions about figure details, as modeled by the formative assessment, to questions that assess whether students can use data to support arguments or hypotheses (as exemplified in Table 2 and Appendix 4 and 5).

Safety issues

None.

DISCUSSION

Field testing

We implemented the Just Figures strategy in an upper division Microbial Genetics course (see syllabus in Appendix 1) with enrollment of 14 to 26 students per quarter. For all figures, students were asked to describe the experimental design, find controls, and summarize results and conclusions (Table 2 and Appendix 3). In addition, more advanced quantitative questions were created for specific figures and were assigned to the students as a handout (Appendix 4). Students were asked to discuss the figures with others in class and then complete this second handout (Appendices 3 and 4) as homework. Handouts were collected the following class and graded for participation rather than accuracy. After six weeks of Just Figures practice, we asked students to answer the questions on the Data Analysis instrument. Students were then assigned one or two papers to read on their own and evaluated using a paper quiz (Appendix 6). For this summative assessment, we chose papers used during the Just Figures exercises, so students were familiar with at least one of the figures from each paper.

Evidence of student learning

To assess whether students met the expected learning gains after being exposed to this exercise, we administered the CREATE survey and the data analysis instrument to Microbial Genetics students. The CREATE survey is a Likert-scale survey with questions about students' confidence, self-reported skills, and beliefs about science (10). A paired-difference *t*-test was performed on each of the survey questions. The difference between post and pre for items related to confidence in reading papers, comprehension of the way research in done, decoding and interpreting primary literature, active reading, data visualization, thinking like a scientist, and research in context were highly significant in the expected direction of post-test gains (*t*-test, $p < 0.01$, Table 4). Since the CREATE survey measured students' self-reported skills, we also administered a tool designed by Sato and Kadandale (Appendix 7) as measurement of actual learning gains in reading and interpreting data. Students showed increased post-test scores. Figure 1A shows that students taking this assessment scored significantly higher after Just Figures practice and just as well as students practicing reading three entire papers in class. The fact that students practicing Just Figures scored just as well as students reading full papers indicates that the Just Figures strategy is as effective as other published methods to teach data analysis skills. The advantage is that it requires less class time investment. The data for post- vs. pre-gains are paired per student. Therefore gains (Fig. 1B) rather than scores (Fig. 1A) were used for statistical treatment comparison. Figure 1B shows that there are significant learning gains in the data analysis quiz score for each of the three years. Students using the Just Figures method were also able to demonstrate figure-reading skills in summative assessments. Figure 2 shows that the distribution of paper quiz scores in the Microbial Genetics course used for this pilot is similar to that of classes that read full papers.

In a post-class open-ended survey, we asked students to comment on what aspect they found helpful about the

TABLE 4.
Summary of changes in the CREATE survey items pre- and post-courses involving discussion of figures from papers and full research articles.

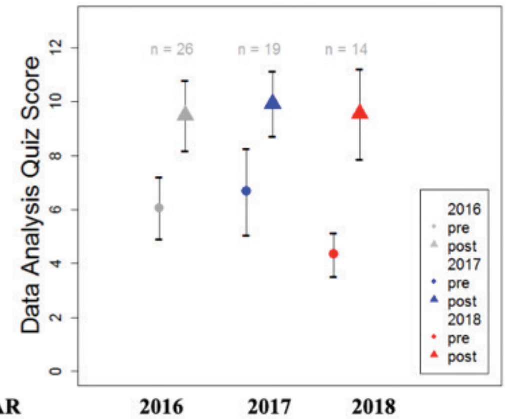
Category[a]	Mean Difference (POST minus PRE)	SD
Confidence in reading and analyzing a journal article	0.6857[b]	0.7581
Understanding of "the way scientific research is done" or "the scientific research process"	0.4444[b]	0.6947
Journal articles are worth the effort	0.0833	0.5542
Decoding primary literature	1.3714[b]	2.1016
Interpreting data	2.1714[b]	2.2027
Active reading	1.25[b]	2.0891
Data visualization	1.3333[b]	2.2804
Thinking like a scientist	1.8333[b]	2.6022
Research in context	0.6944[b]	1.5273
Knowledge is certain	0.9429	3.0577
Ability is innate	0.1944	2.0117
Attitude toward science	0.8824	2.8044

The CREATE survey is a validated instrument published by Hoskins *et al.* (10) consisting of 52 statements to be answered with "I strongly agree," "I agree," "I'm not sure," "I disagree," or "I strongly disagree." All surveys for which both "PRE" and "POST" copies were available were scored on a five-point scale, with "I strongly agree" = 5 and "I strongly disagree" = 1 (or the opposite for negatively written questions), so that a positive POST minus PRE score indicates a gain.
[a]The POST minus PRE score mean responses are displayed. They were compared using a *t*-test with $n = 39$.
[b]Difference is statistically significant ($p < 0.01$).

Just Figures method (see questions asked and sample answers in Appendix 9, $n = 30$). The qualitative responses were thematically classified and tallied. Over one-third (37%) of all responses stated that the exercise simplifies the interpretation of the results. Another 28% indicated that the exercise, in particular outlining of experimental steps, helped them better understand the experimental design. Finally, 25% of the answers pointed out that the exercise clarified the use of controls.

Possible modifications

In our post-class open-ended survey, we also asked students to comment on what aspect of the Just Figures approach they would modify or improve (Appendix 9). Once again, the qualitative responses were thematically classified based on common comments and tallied: 21% of all tallied answers stated that additional information regarding techniques and



Administered as pre/post	Course	6 weeks of Just Figures	Course
Just Figures used?	Yes	Yes	No

FIGURE 1A. Paper analysis instrument response scores displaying the data analysis average score plus/minus two standard errors before (pre) and after (post) courses using Just Figures for the entire course (2016, $n = 26$), Just Figures exercise for 6 weeks (2017, $n = 19$), and a course where students read 3 journal articles and took a paper quiz (as described in Sato *et al.* [12]) (2018, $n = 14$) in a Microbial Genetics course, University of California Irvine. The data analysis quiz instrument can be found in the supplemental material.

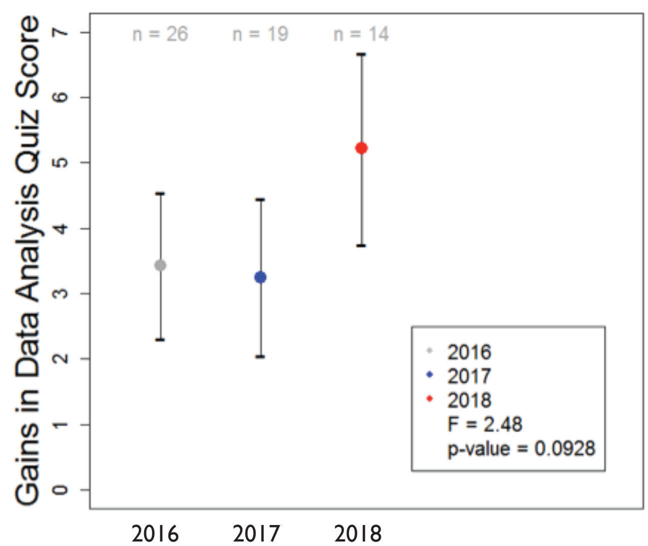


FIGURE 1B. Paper analysis instrument response scores displaying the average gains in the data analysis score (post − pre) plus/minus two standard errors. To test whether there were significant gains in data analysis scores for each year, a one-sample *t*-test was performed with a Bonferroni correction on the Type I error ($\alpha = 0.05/3 = 0.0167$). Each of the three methods had significant gains; 2016 ($t = 6.13$, $p < 0.001$), 2017 ($t = 5.42$, $p < 0.001$), and 2018 ($t = 7.14$, $p < 0.001$). However, there was not a significant difference in the gains on the data analysis quiz score when comparing the course using Just Figures for the entire course (2016), the course using Just Figures for 6 weeks (2017), and the course where students read three journal articles and took a paper quiz (2018) ($F = 2.48$, $p < 0.10$).

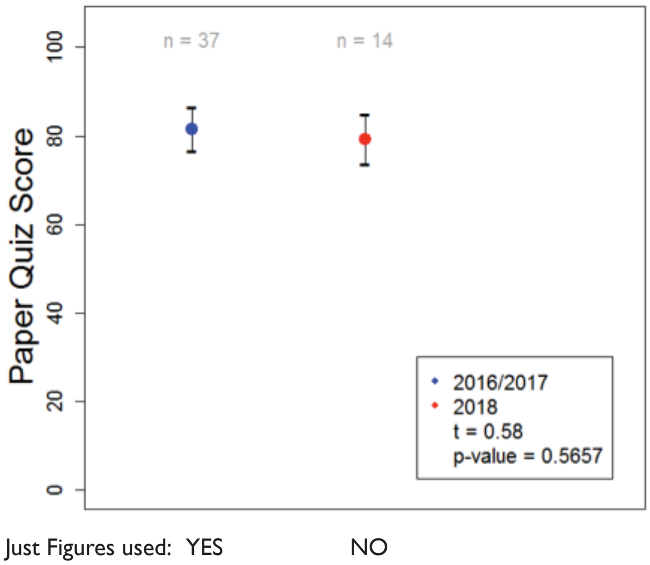


FIGURE 2. Mean plus/minus two standard errors of students' grades on a paper-reading dedicated exam called "Paper quiz." In winter 2016/2017, the Just Figures approach was used (n = 37, mean = 81.58, SE = 2.48). In winter 2018, the paper reading method was used (n = 14, mean = 79.29, SE = 2.81). Although the quizzes used in 2016, 2017, and 2018 were different, they showed a similar distribution of questions at different Bloom's levels, at least 60% of questions ranking in the analyze, evaluate, and create levels of Bloom's Taxonomy (cognitive processes, 27). The quiz was administered toward the end of the course on each quarter it was taught. To test whether there was a difference in paper quiz scores between 2016/2017 and 2018 a two-sample t-test was performed; there was no difference in paper quiz scores when comparing the Just Figures approach and the paper-reading method (t = 0.58, p = 0.5657).

measurements is needed in the legends. Although we did include a short introduction to the assigned figure in our test pilot (Appendix 3), 13% of answers suggested including the article abstract with the assigned figure. Another suggestion was to include a discussion of how students could modify the figure, for example using additional controls or measurements. As students acquired more practice analyzing figures, we noticed that the class discussions organically progressed to critiquing the figure design, legend, or lack of certain controls. Therefore, adding a discussion question addressing re-design could strengthen the exercise.

While this exercise was designed for general lecture courses in which reading full papers is not a main goal, the exercise can be implemented in research-driven courses as well. For those courses (usually upper division) in which paper reading is an important course goal, we propose using this exercise to provide students with formative practice before assigning entire journal articles to read. Incrementally challenging paper-reading exercises have been shown to be effective at easing students into full-paper discussions (9–12, 19). We recommend assigning these first articles with a reading guide that has a figure-centric reading approach (Appendix 8). Students read the paper individually before coming to class and come prepared to discuss the paper with their peers. Recommended class time for this in-depth discussion is 20 to 30 minutes. Following this discussion, groups of two to four students (larger groups for bigger classes) each present one or two figures in front of the class. This is a good way for students to read the entire article, both individually and in groups, while still focusing attention on figures. Groups can choose one of the paper's figures to present or be assigned a figure randomly, making sure the figures are divided among the groups. This approach reduces class time dedicated to presentations, and it models the same figure-centric approach practiced during the Just Figure weeks. Each group presentation can be graded using the rubric in Appendix 8. For large courses in which oral presentations would take a long time, we recommend using immediate feedback forms (IF-AT) to assign a group quiz, which should contain figure-centered questions.

SUPPLEMENTAL MATERIALS

Appendix 1: Example syllabus for a microbial genetics course
Appendix 2: Faculty guide to find suitable papers and figures
Appendix 3: Example of handout to assign a figure
Appendix 4: Example handout/clicker/exam questions
Appendix 5: Answers to exam questions listed in Table 2
Appendix 6: Example paper quiz
Appendix 7: Data analysis instrument
Appendix 8: Full article reading guide and rubric
Appendix 9: Sample of students' comments about the Just Figures exercise

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