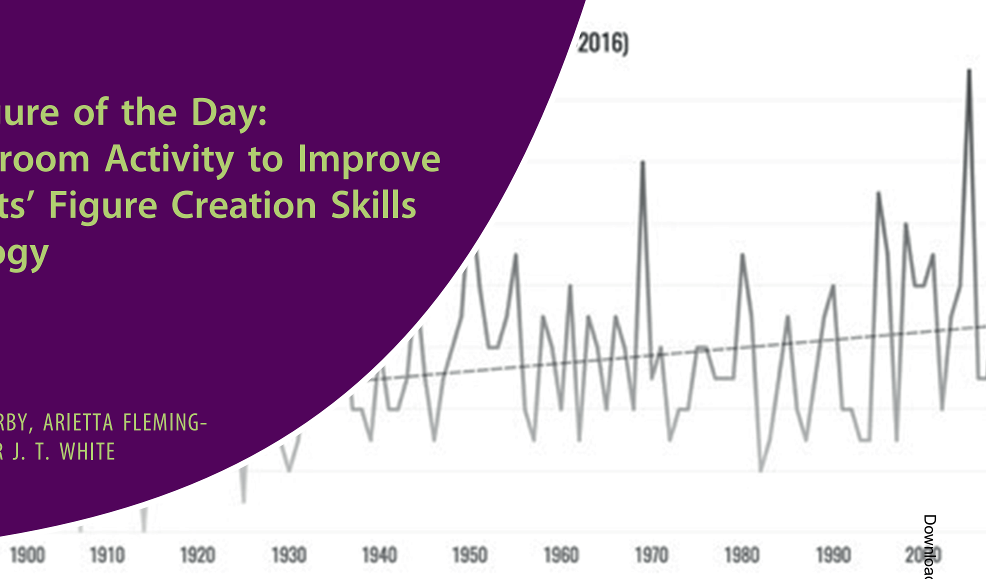
RESEARCH ON LEARNING

The Figure of the Day: A Classroom Activity to Improve Students' Figure Creation Skills in Biology



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Abstract

Creating and interpreting visual displays of data is an important component of quantitative and scientific literacy. We examined a figure-analysis activity called "Figure of the Day" (FotD) and its impact on undergraduate biology students' figure creation skills. The treatment FotD activity required that students interpret a figure with some contextual information missing (e.g., titles, labels, legends). The control FotD activity required that students interpret a figure with no missing contextual information. Students in both the treatment and control groups made significant gains in their figure creation abilities. Bootstrapping of the Wilcoxon signed-rank effect sizes, r, shows large effect sizes for both the treatment (r ± SE = 0.708 ± 0.034) and control (r ± SE = 0.688 ± 0.0395) activities. Students most often reported that the activity's positive aspects were increases in their figure interpretation and creation skills. Commonly reported negative aspects of the activity were that it took too much time and the figures were confusing. Students in the treatment group more often reported that the activity was enjoyable. This suggests that regular interaction with figures in the style of the FotD activity can improve students' figure creation skills in a meaningful and enjoyable way.

Key Words: *Undergraduate coursework; graph interpretation; graph creation; scientific literacy; quantitative literacy.*

○ Introduction

Many undergraduate science courses aim to improve students' quantitative and scientific literacy, which are skills in which students utilize mathematical thinking and scientific understanding to make decisions related to real-world situations (Steen, 2004; Bray Speth et al., 2010; Gormally et al., 2012). In particular, students must call upon both quantitative and scientific literacy in order to analyze, interpret, and create graphs and figures (Shah & Hoeffner, 2002; Bray Speth et al., 2010). Biology courses and textbooks frequently use figures and other visual representations of data, biological concepts, and processes in an effort to aid student learning (Shah & Hoeffner, 2002). Graphs and figures have a high cognitive load for students because they require students to think deeply and analyze the visual representation of data to determine the quantitative relationships between variables (Bowen et al., 1999; Offerdahl et al., 2017). Creating graphs and figures is also a challenging activity for students. Choosing the correct type of figure to display data, scaling the graph axes, and including accurate titles, labels, and legends are skills that college science students often lack (McFarland, 2010). Mastering these skills to be able to communicate clear representations of visual data is a key ability for future scientists (Glazer, 2011).

Biology course instructors should be scaffolding students' interactions with graphs and figures (Offerdahl et al., 2017). Improving students' ability to link visual displays of information with biological concepts and processes requires practice interacting with figures and graphs. That practice can take many forms. Pedagogical approaches that lead students through the process of scientific inquiry are often promoted as important components of developing scientific literacy (Wood, 2003; Glazer, 2011). Inquiry-style activities require students to ask and refine questions, utilize background information, and make and communicate conclusions (Glazer, 2011). Providing students with inquiry-style opportunities to practice figure interpretation and creation skills may thus bolster scientific and quantitative literacy.

Here, we describe an inquiry-style intervention in which undergraduate biology students engage in a challenging and puzzle-like figure-interpretation activity called "Figure of the Day" (FotD). This activity responds to the need to provide activities focusing on visual data that scaffold students' learning, involve active inquiry, and incorporate higher levels of thinking than memorization. We report on the outcome of the activity for students' figure creation skills and their perceptions of the activity.

○ Methods

We implemented the FotD activity as part of a pilot research study to examine its efficacy in improving students' figure creation skills.

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Here, we describe two types of FotD activities as our control and treatment activities. These activities were used once a week for six weeks at the beginning of an undergraduate biology lab session in Introductory Organismal Biology (primarily first- and second-year undergraduates). This project was approved by our institutional review board (IRB no. x17-1160e).

At its core, the FotD activity requires that students analyze a figure and interpret its meaning. For the treatment version of the activity, the instructor prepares two versions of a figure: the first with some key information missing and the other with all the key information present. In our study, the figures were not related to biological sciences but portrayed information on a wide range of topics. This was done with the aim of strengthening students' scientific literacy skills at a broader level, given that disciplines each have their own methods for displaying certain types of data (Offerdahl et al., 2017).

The Figure of the Day: Treatment Activity

The treatment figures were prepared by omitting one or several of the following: figure titles, captions, axes labels, legend text, labels within the figures, and axes unit information (Figure 1A, C). The activity is implemented in a four-step sequence:

1. Students examine the first version of the figure quietly on their own. They are encouraged to observe what information is available and come up with ideas about what variables are being displayed and what purpose any coloring or symbols might serve (1–2 minutes).
2. Students discuss and compare their ideas about what the figure might be representing in small groups of two or three (3 minutes).
3. The instructor debriefs the class, asking for volunteers to share their ideas about the figure's features and meaning. Importantly, the instructor neither confirms nor refutes any suggestions, and instead merely reflects and reframes student ideas. This keeps the discussion open and gives students a chance to further develop and refine their thinking based on the ideas of their peers (10 minutes).
4. The instructor finally displays the original figure, including all of the identifying information that was missing from the first version. Students are then welcomed to give their impressions of the figure, now with the knowledge of what the authors of the figure are attempting to communicate (3–4 minutes).

This step-by-step process of analyzing a figure allows students to make informal hypotheses about the information being displayed, cross-referencing their ideas with their own preexisting knowledge. For example, a student might hypothesize that a figure with blue and red colors is displaying monthly temperature averages for a region. This hypothesis would be based on their prior knowledge that monthly data can be presented in categorical format, and that the colors blue and red are sometimes used to represent cold and warm temperatures. This process encourages students to think beyond the aesthetic features of the figure to the relationships between variables, a skill that novice figure authors struggle with (Picone et al., 2007; Angra & Gardner, 2017).

The Figure of the Day: Control Activity

The second version of the FotD activity acts as a control for the treatment version described above. In this control activity, students analyze a figure and interpret its meaning, but none of the identifying information is missing (i.e., they are only given a figure like the one shown in Figure 1B, D). Students are led through the figure analysis in a similar format to the treatment activity, beginning with individual examinations, progressing to peer interactions, and finishing with a full-class discussion. During the instructor-led discussion phase, the instructor asks students to reflect on the effectiveness of the figure in communicating the intended message. This can include discourse on the type of figure used, the way that colors and symbols are used, and the use of titles, units, and scaling. Finally, once students have had a chance to share their ideas, the instructor shares final thoughts regarding the figure and how the data are being represented. Because students are presented with more information, their cognitive processes may involve the generation of fewer hypotheses and require less cross-referencing with their prior knowledge.

Experimental Design

The FotD activities took place over eight weeks during the fall semester of 2017. Students completed a pre-activity assessment in the first week of the project, then engaged in six weekly sessions of either the treatment or control FotD activities, and completed a post-activity assessment in the project's eighth week. The FotD activities were implemented in 10 lab sections with 20 students each that were taught by five different lab instructors (i.e., graduate teaching assistants); each instructor was responsible for two lab sections. We used a paired design in which each of the lab instructors ran one of their lab sections with the treatment version of the FotD, and the other section with the control version. Thus, the five control lab sections and the five treatment lab sections had the same set of instructors to remove the potential of an "instructor effect" from different instructors implementing the control and treatment FotD activities. There were two additional sections that were given the FotD control and treatment activities that are not reported on here; those two sections were unpaired. This introduced an "instructor effect" for those two sections that we could not account for when reporting our results.

Instructor Training

Two members of the FotD research team (P.J.T.W. and C.K.K.) spent two meetings (one 1-hour meeting and one 30-minute meeting) training the instructors on how to implement the FotD treatment and control activities to ensure consistency of activity application across lab sections. This training included a detailed description of the activities, along with the modeling of each activity three times. These two members of the FotD research team (P.J.T.W. and C.K.K.) then met with the course lab instructors on a weekly basis for the duration of the project to review the FotD activity procedures and to introduce the figures for the coming week. To help prepare, each instructor was also provided an "instructor guide" to their assigned figures with relevant background information about the figure and a list of questions that they could ask students during the debrief stage of each activity (Box 1).

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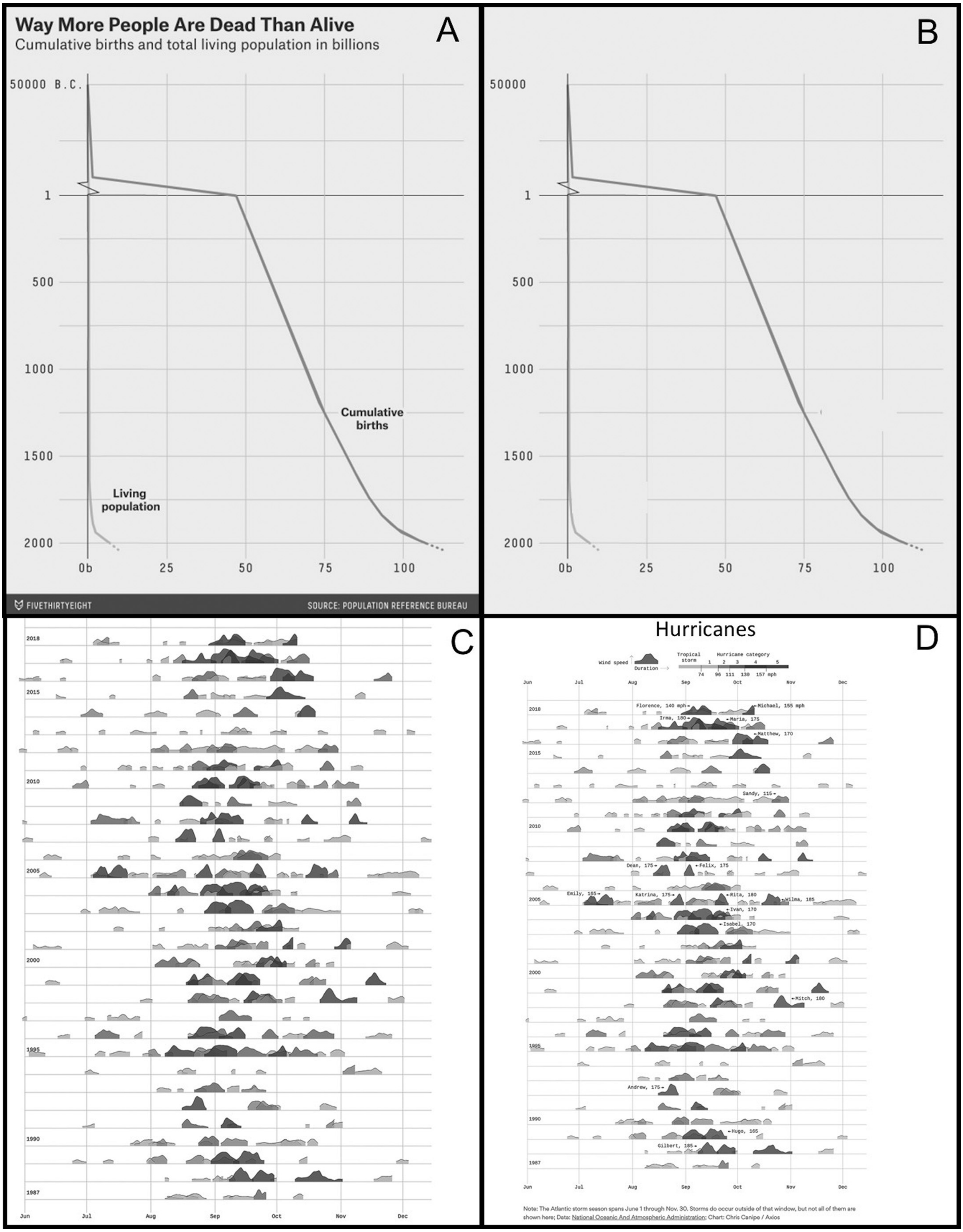

Figure 1. Examples of the FotD activity. In a treatment activity, students would be asked to analyze a figure with identifying information missing (e.g., **A** or **C**). After the activity, the second version of the figure would be revealed (e.g., **B** or **D**). In the control activity, students would be asked to analyze only the second panel of each figure above (i.e., **B** or **D**). Panels A and B are adapted from Chalabi (2015). Panels C and D are adapted from Canipe (2017).

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Box 1. Sample instructor guide for a figure used in the FotD activity. The guide shown here is for the cumulative population figure seen in Figure 1A, B (source: https://fivethirtyeight.com/).

Instructor Guide: Living Population Compared to Cumulative Births

Features

- x-axis: Population in billions.
- y-axis: Year.
- Green line labeled "Cumulative births" shows births since 50,000 B.C.
- Yellow line labeled "Living population" shows currently living population.
- Green line increases with a higher slope than yellow line.
- Both lines become exponential at ~1900.
- Green line increases the whole time.
- Yellow line starts level, then increases.

Possible Questions to Ask

- What does the author of this figure want to communicate?
- Is the author effective in communicating this?
- Why the break in the graph before year 1 A.D.?
  - Break is to show scale of years better.
- Why does the green line increase so much during that time?
  - Green line increases because many years are compressed into that small space.
- Why don't the yellow line and the green line appear to increase at the same rate?
- Could this graph be represented differently? (Bars/pie? Scatterplot? No shading?)

Assessments

We used two simple assessments to (1) gauge the impact of the treatment and control activities on students' figure creation abilities, and (2) solicit students' perceptions of the control and treatment activities.

To measure the impact of the FotD activities on students' figure creation abilities, students completed a pre- and post-FotD activity figure-drawing task that read as follows:

Create a figure that best represents the following:

- The Fictus Fish lives in the ocean at a depth between 4 and 10 ft; a single individual has an average of 15 offspring every year.
- The GelCap Jellyfish lives in the ocean at a depth between 8 and 15 ft; a single individual has an average of 300 offspring every year.
- The Mountain Whale lives in the ocean at a depth between 15 and 50 ft; a single individual has an average of 2 offspring every year.
- The 7-Point Starfish lives in the ocean at a depth between 2 and 30 ft; a single individual has an average of 1000 offspring every year.

This task was given to students before and after the six-week figure-set implementation. Students did not receive feedback on their pre-FotD assessment figures. Thus, their decision to make an identical or new version of their drawing for the post-assessment was independent of whether they thought their first figure was correct or incorrect. This question required that students represent three variables (a fictitious marine species, its reproductive output, and the depth at which it can be found) on a single figure. Student figures were scored in one of seven categories (Table 1). The rubric incorporated the "completeness" of a figure in addition to correctness. For example, a figure that was technically correct but omitted one of the variables was not scored as correct. After designing the rubric, two members of the FotD research team (C.K.K. and P.J.T.W.) independently applied the rubric to a set of 40 student figures and provided identical scores in 38 of 40 cases (95%). The rest of the scoring of student figures was done by C.K.K. and P.J.T.W.

After scoring the pre- and post-FotD figures, we conducted statistical analyses to determine whether the gains from pre- to post-FotD were different for the control vs. treatment FotD activities. Prior to the analysis, we removed students with a score of 6, 7, or 8 in the pre- or post-project drawings (n = 27). These students did not follow the instructions of the assignment, and it was not possible to logically conclude that a score change represented an improvement or a decline in figure-making abilities. Conversely, scores of 5, 4, 3, 2, and 1 represent a hierarchical evaluation of student figures from the poorest (5) to the best (1) representation of the data. Following these two filtering decisions, we were left with 82 students in the control group and 81 students in the treatment group.

We first ran a paired Wilcoxon signed-rank (WSR) test to determine whether there were differences from pre- to post-FotD *within* each group (i.e., a WSR test for each of the control and treatment datasets). A WSR test is analogous to a t-test but is appropriate for paired, ranked nonparametric data. Because students were nested in class sections, and students in the same class are more likely to experience the same instructional environment, it is important to account for the non-independence of students in the same class section (Paterson & Goldstein, 1991; Kreft & de Leeuw, 2002; see also Eddy et al., 2014). We therefore addressed this nested or hierarchical structure of the data in our WSR tests by incorporating a random effect that accounts for the variation between classes within the same treatment group (package "coin" in R; Hothorn et al., 2008). The WSR tests for each group provided information about changes from pre- to post-FotD in the treatment group and in the control group but did not inform whether or not the change from pre- to post-FotD was different *between* the two groups. To test for differences between groups, we used a nonparametric bootstrap of the WSR test (n = 10,000) for each group (R Development Core Team, 2011; Canty & Ripley, 2017). This provided a mean effect size for each group (i.e., a representation of the average difference between pre- and post-FotD scores) along with standard error estimates.

For the second assessment, students responded to two open-ended questions:

1. List some of the **positive aspects** of the Figure of the Day activity.
2. List some of the **negative aspects** of the Figure of the Day activity.

Students' answers were given anonymously, but each respondent included their lab section, which allowed their responses to be sorted into treatment and control groups. Responses were coded into categories of either positive or negative aspects, with grounded

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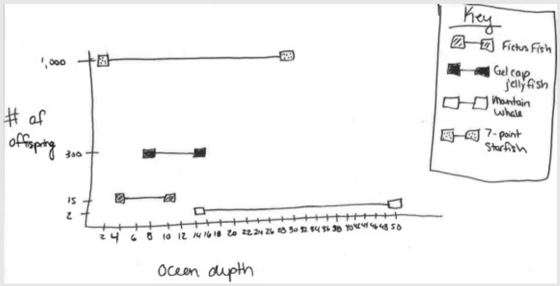
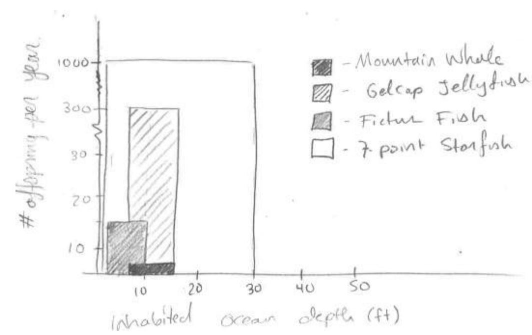
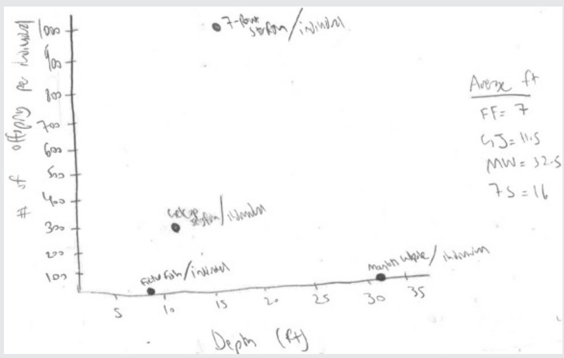
Table 1. Rubric for scoring student figures.

Score	Score Description	Sample Student Figure	Figure Description
1 – Correct	Correct graph, showing all three variables. This typically involves a single line showing each species' average offspring, across a range of depths, with an appropriately labeled scale, and including an indication of which species is which line.		The student depicts a range variable on the x-axis and an integer variable on the x-axis. The categorical "species" variable is denoted by labels next to each line. The placement of numbers on the y-axis implies a log-transformed or similarly transformed axis.
2 – Correct, but can improve	Correct graph, displaying three variables, but the graph can be improved. For example, there may be minor scale issues, bar graphs shaded and overlapping, bars showing a width of average offspring values rather than one value.		This figure is a close approximation of the preferred correct image. The range variable (depth) is depicted on the x-axis, while the integer variable (offspring) is shown on the y-axis. This figure could be improved by showing ocean depth as a single horizontal line, rather than a bar that is connected to the x-axis.
3 – Incorrect, attempts to show three dimensions	Incorrect graph, but the student attempted to show three variables. The scale may have major issues, data may be displayed incorrectly, data may be displayed in a way that is not typical of scientific graphs (for example, students putting a dot for each species' average offspring, and connecting those dots with a line). Students showed series of symbols or units that don't have meaning (rather than a line showing depth range).		The student includes both depth and offspring in their graph as continuous variables, along with *species* as a categorical variable. The score of 3 recognizes that all three variables are included in the graph, but that the graph is not correct (depth should be shown as a range).

(continued)

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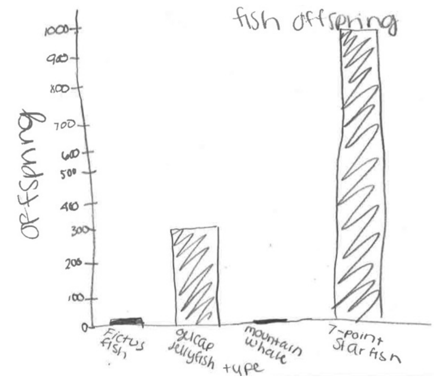
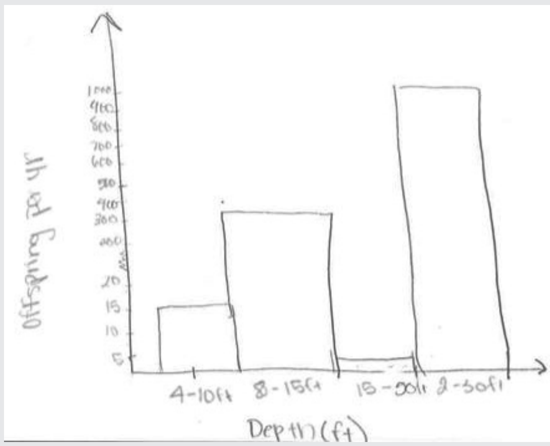
Table 1. Continued

Score	Score Description	Sample Student Figure	Figure Description
4 – Incorrect, attempts to show two dimensions	Incorrect graph where student has shown only two variables. This includes instances where continuous variables are converted into categorical variables (i.e., offspring or depth).		The student shows only the relationship between *species* and *offspring*.
5 – Incorrect, attempts to show one dimension	Incorrect graph where student has only shown one variable.		The student shows the offspring as a visual variable on the y-axis. However, the depth is shown as a categorical variable and thus was not considered to be depicted visually. Species information is not present.
6 – Did not follow instructions, more than one figure (correct)	Student has provided more than one figure, but the figures that are shown are correct.	Not analyzed	
7 – Did not follow instructions, more than one figure (incorrect)	Student has provided more than one figure, and one or more of the figures that the student has provided is not accurate or correct.	Not analyzed	
8 – No figure	Student did not draw a figure.	N/A	

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theory guiding the development of categories based on the wording of student responses. Categories were updated iteratively throughout the coding process.

○ Results

Figure Creation Assessment

There was a notable improvement in students' figure creation skills after the six-week activity period (Figure 2). In the control sections (n = 82), the average figure score was 2.5 (median = 2) at the beginning of the study, improving to an average score of 2.2 (median = 2) at the end of the study (WSR test, Z = 8.81, $P < 0.001$). In the treatment sections (n = 81), the average figure score was 3.0 (median = 3) at the beginning of the study, improving to an average score of 2.5 (median = 2) at the end of the study (WSR test, Z = 9.01, $P < 0.001$). Comparing effect sizes can give an indication of whether the improvement in one group was bigger than the improvement in the other; a larger effect size indicates a larger difference between the pre- and post-study figure scores. Bootstrapping the WSR tests can provide a standard error estimate for each effect size. The mean (± SE) bootstrapped effect size,

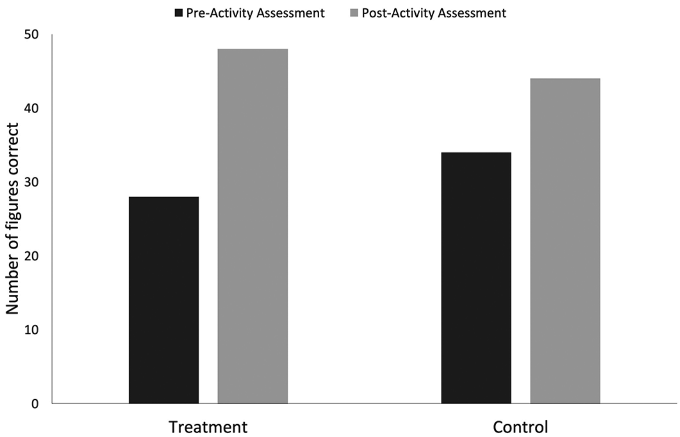

Figure 2. Total number of correct student figures from pre-activity to post-activity. Figures were scored on a scale of 1–5 according to the rubric in Table 1. A "correct" figure earned a score of 1 or 2. The number of students whose figures were scored as a 1 or a 2 on the post-assessment increased in both treatment and control sections.

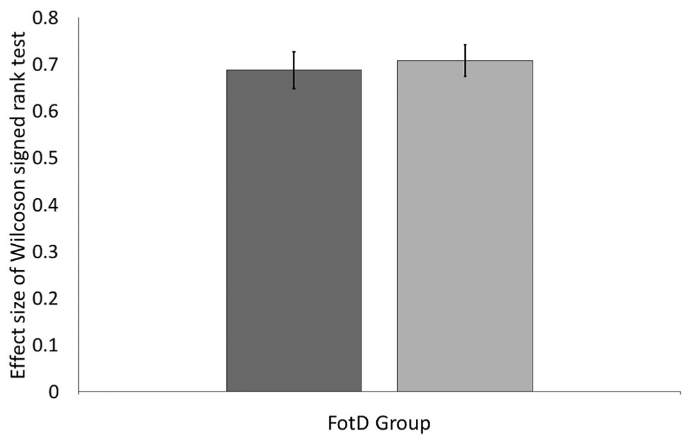

Figure 3. The change in figure scores (measured by effect size, r) in the treatment group and the control group both showed large effect sizes (>0.5). Error bars give bootstrapped 95% confidence intervals.

comparing pre- to post-FotD figure scores in the control group, was 0.688 ± 0.0395 (Figure 3). This is a large effect size according to Cohen's criteria (Field, 2013). The mean (± SE) bootstrapped effect size, comparing pre- to post-FotD figure scores in the treatment group, was 0.708 ± 0.034. For the treatment group, this is also a large effect size (Field, 2013).

Student Perception Assessment

We collected 195 total responses from students about the positive and negative aspects of the FotD activity (treatment n = 98, control n = 97). Students listed between zero and three aspects of the activity for each question. The two most commonly suggested positive aspects of the FotD treatment activity were that it improved students' figure-interpretation and critical-thinking skills and that it was fun (Table 2). The two most frequently mentioned positive aspects of the FotD control activity were that it was helpful in students' figure-interpretation and critical-thinking skills, and that it improved students' figure-creation skills. Other common positive features of the FotD control activity were that it was an effective warm-up activity and that it exposed students to many different types of graphical data displays.

While the two most commonly mentioned negative aspects for the treatment and control activities were the same (took too much lab time, figures were too confusing), there are interesting differences in other categories of students' responses. For example, nearly 20% of the treatment students reported that there were no negative aspects of the FotD treatment activity, while only 10% of students in the control section felt similarly. Other frequently reported negative aspects were that the FotD activity was boring and that it did not facilitate learning gain.

Beyond the five most common positive aspects of the FotD activity, students also reported that it allowed collaboration with classmates, included interesting non-biology topics, encouraged creative learning, and was easy. One student in a treatment section reported that there were no positive aspects of the activity. Additional reported negative aspects of the FotD activity were collaboration with classmates, that figures were difficult to see, that the figure topics were not linked to course concepts, and that students would have preferred to do the activity for more weeks of the semester. One student in a control section felt the figures were not challenging enough.

○ Discussion

In this study, we explored a classroom figure analysis activity, its impact on students' figure creation skills, and their perceptions of the activity. We found that students in the treatment and control activities demonstrated significant gains in their figure creation abilities. Students in the treatment activity, which involved exploring figures with little contextual information, enjoyed the activity more than students in the control activity sections. The FotD activities can improve students' scientific and quantitative literacy through improved figure creation skills, and students may prefer to do so in the style of the treatment activity.

Both the control and the treatment groups demonstrated a significant improvement in their figure creation skills as demonstrated by significantly improved post-scores on the figure creation assessment. When students engage in either FotD activity, they improve their figure creation skills. However, it is not clear whether interacting with the treatment figures, whereby students attempt to determine what information is being presented, has the potential to impact these skills more (Figure 3). While not statistically significant, more students' figures improved in the treatment than the control sections (Figure 2), and this may warrant further exploration with additional assessments or longer use of the classroom intervention. There are also theoretical reasons for further study of the impact of the treatment activity. Pedagogical methods in which students are first asked to make a scientific prediction based on their current understanding before being told the correct answer can lead to more effective retention of the material than when an instructor simply gives the correct answer (Gunstone & White, 1981; Liew & Treagust, 1998). Creating an "information gap" in a person's mental model by omitting essential information might lead to increased engagement with the correct answer when it

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Table 2. Students' most common responses to the Figure of the Day treatment and control activities. The top five coded responses to the positive and negative aspects of the FotD activity are displayed, with the percentage of respondents who indicated each aspect from both the treatment (n = 98) and control (n = 97) sections.

Positive Aspect	Sample Quote	Treatment Respondents	Control Respondents
Improved figure interpretation and critical thinking skills	"It allowed me to critically analyze all the different types of ways data can be represented."	47%	64%
Fun, engaging, enjoyable	"It was really fun."	33%	14%
Exposure to different figure types	"Get to learn more about different figures and see different ways figures can be represented."	20%	28%
Improved figure creation skills	"It helped us figure out how to make our graphs communicate better."	17%	31%
Effective warm-up	"Gets the mind thinking before lab starts."	17%	9%
Negative Aspect	**Sample Quote**	**Treatment Respondents**	**Control Respondents**
Took too much lab time	"Sometimes I felt like we could have used the class time for other things."	37%	26%
Figures were confusing, too complicated	"The graphs were so horrible that they were funny and sometimes were hard to read and understand."	29%	30%
None	"No negative aspects."	18%	10%
Pointless activity, no learning gain	"I thought it was not very useful and did not help how I looked at graphs."	10%	15%
Boring or repetitive	"It got a little repetitive by the end of the semester."	8%	13%

appears (Seifert, 2002). Similarly, by removing figure labels and legends, the FotD treatment might also create an information gap that helps motivate students to fill in the missing information about the figure.

The treatment FotD activity also potentially shares more similarities with the process of creating figures than the control activity. In the treatment activity, students are likely to generate more hypotheses about what the figure may be communicating and to alter those hypotheses more drastically based on feedback from instructors and other students. This is similar to the process of analyzing and creating visual displays of scientific data, whereby students iteratively construct and adjust mental and then physical representations of the data (Glazer, 2011).

Students may have been more engaged in the treatment version of the FotD activity compared to students in the control sections (Table 2). This makes intuitive sense because the control activity is in line with regular classroom activities in which students are simply analyzing given information. However, the treatment activity is more puzzle- or game-like, with students offering guesses and the instructor then revealing the true answer. Students' increased interest in the treatment version of FotD may indicate that they were more likely to be engaged in active learning during the activity. Active learning with figures is important in developing students' figures creation skills (McFarland, 2010).

Interestingly, students in the control sections were more likely to report that the FotD activity contributed to their learning of figure interpretation or creation skills than students in the treatment sections. This was not supported by our results, which showed large effect sizes of students' improvement in figure creation skills across both the treatment and control sections. One potential explanation for this finding is that students most often listed only one or two of the most salient characteristics of the activity. Because the treatment activity was puzzle-like, the enjoyable nature of the activity was more salient for many students than the learning gains. Many students then would list only that feature – that it was enjoyable – and not discuss other aspects of the activity. For students in the control activity, the most salient feature then appears to be the learning gains. This is supported by the fact that similar numbers of students in the treatment (10%) and control (15%) listed that the activity was pointless or had no learning gains.

Overall, this study shows that students enjoy engaging with and critiquing figures in the FotD activities, and that both the treatment and control activities improve students' figure creation skills. As students progress from introductory biology courses into

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biology careers, they will more heavily utilize skills of interpreting and displaying information visually. The FotD activities provide an opportunity for instructors to facilitate and scaffold that learning by leading students through discussions about different types of displays of visual data.

○ Future Directions

For this pilot study, we developed additional assessments related to students' figure interpretation and analytical skills, growth and fixed mindset, and Likert-type assessments of students' perceptions of the activities. However, due to reliability issues with the assessments and the lack of a true control (where a group of students receives no figure activity), we did not report on these measures. A future study could improve upon these measures to provide a more complete picture of the types of gains students receive by engaging in different variations of graphing activities.

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