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# "This figure could be better, but how?"

## Advancing design critique in STEM research labs

**Keywords:** **scientific visualization, design critique, communicating science, visual communication in science, graphic design for scientists**

**This paper considers whether scientists can improve their visual design abilities by participating in critiques. In design education, a critique is a class session where designers present their work-in-progress and receive feedback from faculty, peers, and invited critics. In this study, we show that an intervention consisting of (1) an introduction to visual principles, (2) an explanation of critique methodology, and (3) participation in a group critique led to a significant increase in both the quantity and quality of feedback that scientists provided on a set of figures. These findings indicate that critiques can be a valuable practice for scientists to integrate into their research labs.**

> Science is a fundamentally visual endeavor. It pivots on the material—whether that is an atom, a gene, a crystal, a whale, or a distant galaxy. Its aim is elucidation. Thus, communicating research has always been predicated on combining image and text to share discoveries, ideas, and observations. —Geoffrey Belknap (2019)

Despite broad recognition of the value and role of visuals in science (Frankel, 2020; Khoury et al., 2019; Iwasa, 2016; Rodríguez Estrada & Davis, 2015; McInerny et al., 2014), education in STEM (Science, Technology, Engineering, and Math) fields rarely includes visual design training. Lynda Walsh and Andrew Ross (2015) surveyed members of five national STEM research organizations and observed that less than 5% of the 144 respondents reported learning how to design visuals in a classroom environment.

This lack of training is unfortunate, because in modern-day scientific communication, researchers increasingly need to share information in visual formats. Besides figures for academic papers, presentations, and grant proposals, scientists are expected to make graphical abstracts that attract readers and highlight the key findings of a paper; they are also encouraged to create visuals that can be used on social media to quickly and simply explain their research.

Because visual design education is largely absent in disciplinary STEM curricula, most scientists-in-training learn how to design visuals "on the job," when they transition from the classroom to the world of research by joining laboratory groups. In this setting, scientists, by necessity, create visuals to communicate their research findings. Advisors and senior colleagues guide junior scientists in this activity by example and through direct instruction. Much of the training and exposure occurs in lab group meetings, when researchers present and receive feedback on their work-in-progress, which includes figures in manuscript drafts, slide presentations, and scientific posters (Ostergren, 2013).

However, because many scientists have little or no visual design training, feedback offered to improve visuals within lab groups can be misguided or inaccurate. In interviews, STEM graduate students who did have design training described conflicts with advisors who were unaware of basic principles of visual perception, and their frustration with established scientific conventions that discouraged the development of more effective designs (Clarkson, 2014).

To improve visual communication in science, many authors have created guides, books, and workshops targeted toward researchers (Frankel & DePace, 2012; Wong et al., 2015; Rougier et al., 2014; Rolandi et al., 2011; Christiansen, 2020). However, those in STEM fields may have difficulty finding these resources and evaluating their quality and relevance to their work. Even when a reliable source of visual design information is identified, scientists still face the difficulty of translating theory into practice. Design principles are broad guidelines that explain how to organize visual elements so that information is logically and progressively revealed. A scientist-designer may understand the overall concepts involved in creating a clear visual hierarchy, yet still struggle to select the specific shapes, sizes, positions, spacing, and colors for multiple elements within a figure.

Given these obstacles, it is perhaps unsurprising that many scientific figures are cluttered and poorly organized, with unclear emphasis and unintended color associations. These visual problems are not merely aesthetic. Studies have shown that viewers are slower and less accurate when extracting information from charts and graphs that use weak or conflicting visual encodings (Cleveland & McGill, 1985; Lin et al., 2013; Borkin, 2011).

## 1. A potential solution: Design critiques

We believe that the effectiveness of visual communication in science would be improved if STEM research groups would: (1) share a common understanding of visual design principles, and (2) apply these principles to their scientific figures. As it may be unreasonable to expect a broad scale restructuring of curricula across STEM education to include formal visual communication training, we propose that individual laboratory groups self-cultivate their design abilities by adopting a key practice from the design classroom: critiques.

In design education, a critique is a class session where designers present their work-in-progress and receive feedback from faculty, peers, and invited critics. While the immediate goal of a design critique is to advance the work being shown, on a broader level, critique participants increase their knowledge of visual design by (1) assessing if a design is effective or ineffective at meeting a stated goal, (2) imagining and articulating potential solutions to the problems they identify, and (3) suggesting processes or referring to references that could lead to or inspire a solution. (Dannels & Martin, 2008).

The knowledge that participants gain during design critiques may relate to "understanding through explanation." Learning scientists believe that explaining a concept helps learners to update and refine their mental models as new information becomes integrated with prior knowledge (Roscoe & Chi, 2007; Bisra et al., 2018). Additionally, when answering questions and providing feedback to others, learners may become aware of gaps in their understanding that need to be addressed (Bargh & Schul, 1980).

Although learning through explanation has been examined extensively in research literature, to our knowledge there have been no efforts to examine the utility of design critiques in improving scientific figures.

Therefore, to validate the use of design critiques in lab groups, our study seeks to answer the following research question: ***Can scientists improve the quantity and/or quality of their visual design feedback by participating in design critiques?***

## 2. Method

### 2.1 The critique intervention

We recruited scientist-participants from four STEM lab groups at a large R1 university in the Pacific Northwest of the United States. All lab groups consisted of faculty, undergraduates, graduate students, and postdoctoral associates in various fields of science and engineering. The faculty leading the recruited lab groups had previously contacted us to discuss improving the scientific figures produced by their group. Each lab group had six to eleven members, for a total of 35 individuals. Of the 35 individuals, eight (23%) reported having prior visual training (either a single workshop, a single college-level course, or work experience on a high school/college newspaper or science magazine).

Before the critique intervention, a visual designer on our team observed 15–20 regular lab group meetings over three months (meetings were held via internet video-conference due to COVID restrictions). These observations allowed us to assess each lab's existing knowledge of visual design and current visualization practices, while also establishing the trust and rapport necessary for facilitating a design critique.

The actual critique intervention consisted of two workshops (held as internet video-conferences due to COVID restrictions). The first workshop was one hour long and its goal was to introduce participants to visual design principles and best practices for design critiques. The second workshop was 30 minutes long and its goal was for participants to learn how to give and receive feedback that was based on design principles to improve in-progress drafts of scientific figures.

To prepare the scientists for the two workshops, we asked all lab group members to complete three readings in advance: (1) a book chapter on visual design principles (Cairo, 2012, Chapter 6); (2) an article on soliciting and accepting feedback (Manzoni, 2016); and (3) an article on structuring design critiques (Berkun, 2003). We also asked participants to watch a six-minute video on giving and receiving feedback during design critiques (Berkun, 2011). These materials were chosen for their content, accessibility, and brevity.

During the first workshop, the designer who had observed the earlier lab group meetings introduced scientists to: (1) fundamental elements of visual design: contrast, hierarchy, space, proximity, unity, and flow; (2) basic visual composition, including how to structure a layout, creating effective backgrounds, selecting, ordering, and positioning images, and the importance of "white space;" (3) typographic principles, such as type structure, type weight, and letter spacing; and (4) color theory: the color wheel, color schemes and color attributes (hue, saturation, lightness, value, and contrast). Specific resources for working with color (e.g., Adobe Color) were also shown and discussed.

During this first workshop, each visual design principle was illustrated with a flawed scientific figure. As would be normal practice during a design critique, participants were asked to identify problems with the figure and offer suggestions for improvement. Often, scientists were able to see broad visual issues (e.g., "hard to follow" or "too complicated") but struggled to imagine and articulate specific repairs. To stimulate participants' thinking (and to broaden their mental library of possible solutions), we followed the flawed figure with an alternate version of the same figure that had been redesigned by a professional graphic designer. For example, a flawed and repaired version of a figure with poor visual "flow"

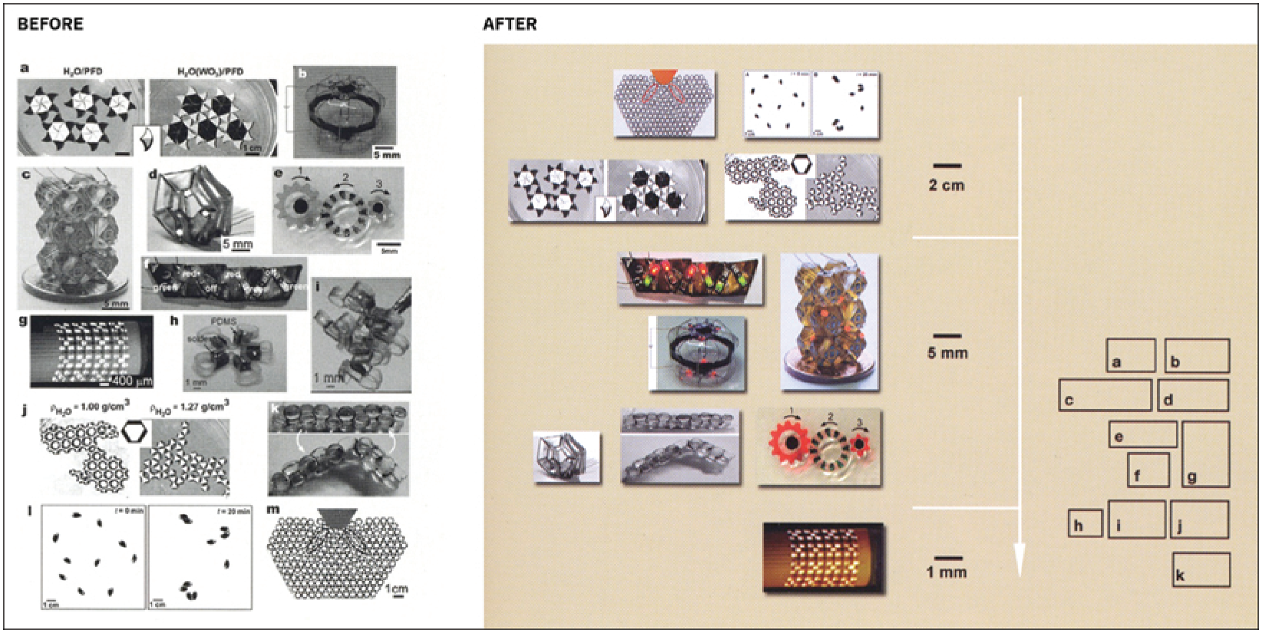


**Figure 1.** Two variations of a scientific figure designed for a grant application. The communication goal was to demonstrate the lab's ability to fabricate a variety of self-assembled structures at different sizes. Using a single scale reference helps the viewer understand the relative sizes of the devices being shown. Reproduced with permission from *Visual Strategies* (Frankel & DePace, 2012, 70–71)

is shown in Figure 1. In previous visual design tutoring sessions that we have conducted (O'Mahony, 2019), displaying multiple versions of a figure helped scientists break through "tunnel vision" and recognize a larger realm of visual possibilities.

At the end of the first workshop, after the discussion of specific design elements and visual principles, participants were asked to verbally critique a final group of three scientific figures that had multiple visual issues. This last exercise prompted scientists to recall and apply their newly acquired design knowledge, with the goal of consolidating their understanding.

The second workshop occurred approximately two weeks after the first workshop. The designer leading the workshop began with a review of critique etiquette and structure. Then, three to four scientists presented their figures-in-progress to the rest of the lab group for critique. Each presenter had 30 seconds to describe the key message of their figure and to indicate the kind of feedback that they wanted. Presentation time was intentionally brief to maximize the time for the critique discussion, and to build the expectation that scientific figures should be largely self-explanatory. The subsequent discussion/critique among lab group members was approximately five minutes per figure.

## 2.2 Assessing the critique intervention

To measure the effectiveness of our critique intervention, we asked all scientist-participants to provide written feedback on a group of five figures both before and after the two workshops. For authenticity, the selected figures were sourced from science literature or academic posters. We selected these five examples because they were accessible in content (could be understood by non-specialists), and because they demonstrated common visual design errors that have been identified in multiple guides to designing effective scientific figures (Wong et al., 2015; Hunnicutt & Krzywinski, 2016). We asked six professional visual designers to find and describe all the design errors in these five figures. This panel identified the following issues: inconsistent labeling, undifferentiated typography, lack of visual hierarchy, unclear symbology, clutter and complexity, inconsistent color coding, overuse of arrows, poor visual grouping, and lack of visual alignment.

We used an online survey to collect written responses from the scientist-participants. We first asked scientists to describe what they thought was the main message or key "takeaway" for each scientific figure. We hoped this would put the focus of their feedback on achieving clear communication. Then, scientists were asked to describe "what (if anything) they would suggest changing to make the figure clearer and/or more engaging to an audience of scientists", as shown in Figure 2.

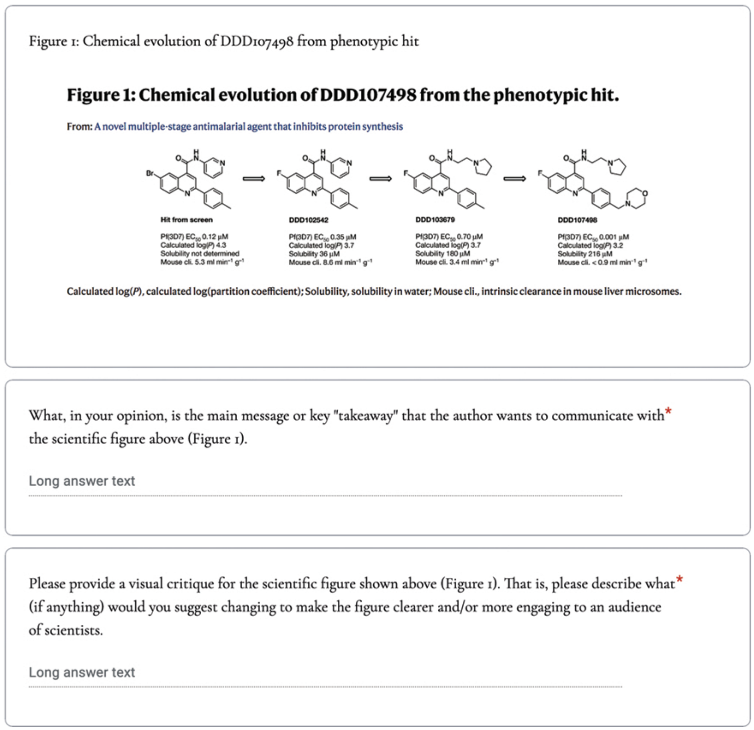


**Figure 2.** In an online survey, scientists were asked to provide a visual critique on five scientific figures before and after the critique intervention. All five figures were sourced from published scientific papers or academic posters. The figure shown here is reproduced with permission from *Nature* (doi: 10.1038/nature14451)

Due to the difficulty of finding or creating two sets of parallel figures with identical visual issues, we used the same five figures both before and after our intervention. Using the same figures ensured the participants were presented with the same visual issues. Figures were presented in the same order in both the before and after conditions; the simplest figure was shown first, followed by figures of increasing complexity.

In our analysis, we chose to focus on problem identification and suggestions as two key indicators of feedback quality. This classification system aligns with the two main purposes of design critiques, which are: (1) to find errors that could cause visuals to be misunderstood, and (2) to advance ideas or processes for fixing those errors.

Two members of our research team reviewed and coded the written critique responses from each scientist in both the before- and after-intervention surveys. The unit of analysis was any phrase, sentence, or paragraph that represented a coherent thought or idea about the scientific figure. Both coders worked independently to sort feedback into three categories: problem identification, suggestions, or neither. Problem identification was defined as feedback that identifies a visual communication problem in a scientific figure (e.g., "the figure is busy" or "it is not clear what the arrows mean."). Suggestions were defined as feedback that describes an action that can be taken to improve a scientific figure (e.g., "eliminate the middle two columns" or "put all the legends in one place"). The "neither" category included comments that were neither problems nor suggestions (e.g., "the rat graphic is cute"). Of the 35 scientists who participated in the critique intervention, 26 completed both the before and after surveys (74%). These 26 participants generated 952 units for coding.

The two coders agreed in their independent ratings on 86% of the feedback, with a Scott's pi intercoder reliability score of $\pi$=.77. The two coders then discussed and resolved all disagreements. The 100% mutually agreed-upon coding was used in our final analysis.

## 3. Results

### 3.1 Increased feedback quantity in both problems and suggestions

As shown in Figure 3, across all five figures, scientists were able to identify more problems and make more suggestions after participating in the critique intervention. Scientists increased the average number of problems that they identified in a figure by +30%. The average improvement in suggestions was larger; scientists were able to more than double (+107%) the number of suggestions they made to improve a figure. Because our two dependent measures, problems identified and suggestions made, are highly correlated ($r$ = .49), we ran a multivariate analysis of variance statistical test (MANOVA). A reliable statistical difference in mean vectors was found between the critique before the workshop and the critique after the workshop across the two dependent variables, $F(2, 24) = 11.20$, $p < .001$, $\eta_p^2 = .483$. In follow-up univariate ANOVA, reliable statistical differences were found for both number problems identified across sessions, $F(1, 25) = 6.02$, $p = .021$, $\eta_p^2 = .194$, and for number of suggestions made, $F(1, 25) = 20.88$, $p < .001$, $\eta_p^2 = .455$

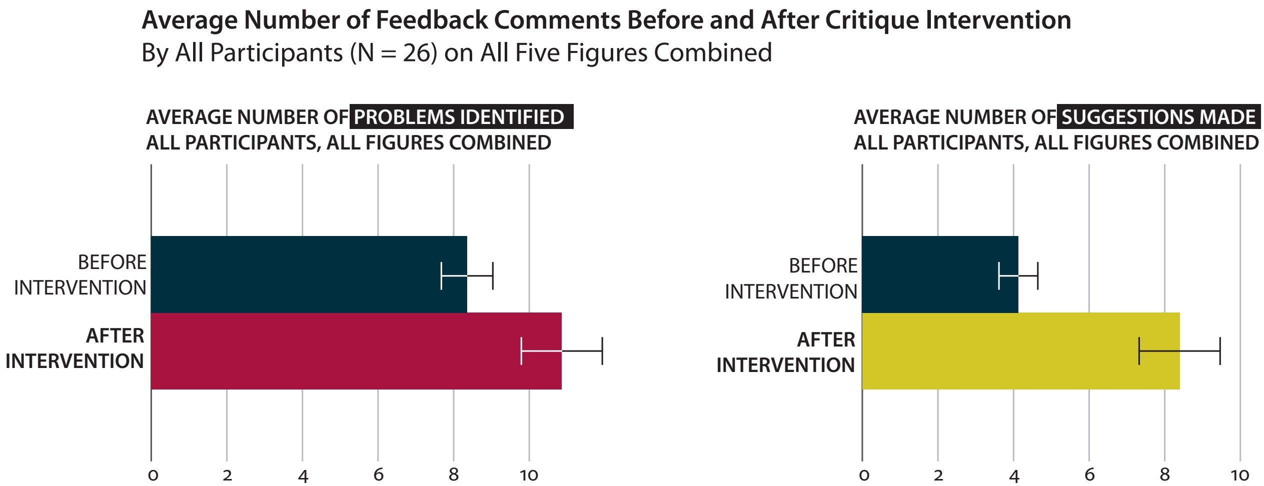


**Figure 3.** The average number of feedback comments (problems identified and suggestions made) before and after the critique intervention, with standard error. Across all five figures, scientists were, on average, able to identify more problems (+30%) and make more suggestions (+107%) after participating in the critique intervention

## 4. Discussion

### 4.1 Nature of the Improvements

These positive results are very encouraging as they suggest that lab groups would indeed benefit from adopting a regular practice of design critiques. We recognize it is possible that participants would identify more issues after the intervention simply by revisiting these figures. However, it is our belief that nearly all the differences between the before and after conditions can be attributed to the training given to the scientists. In future research we could confirm this by having a control condition where participants are given training in a topic other than design.

While a quantitative improvement is good, understanding the qualitative changes in feedback may provide additional insights that enable the refinement and optimization of critique methods for scientific researchers. Below, we describe five qualitative differences in feedback that we observed from pre- to post- intervention.

#### *4.1.1 Scientists progressed from merely identifying visual problems to actively proposing design solutions*

Specifically, after the intervention we saw a larger increase in suggestions vs. problem identification. In our view, suggestions are highly beneficial (superior to problem identification) because repairing a visual is harder than simply recognizing its flaws. Intelligent and experienced readers of academic papers can usually tell if a figure is not working, because they personally find the figure hard to understand. However, without visual design training, it can be difficult for viewers to conceive of new ways to construct the figure that addresses the issues identified.

The gap between recognizing and solving a visual problem was aptly summarized by a scientist-participant in our survey, who stated: "***I know the figure could be a lot more clear because it took me a while to figure out what the takeaway was, but I'm not sure how to improve it***."

Our perspective aligns with Valerie Shute's comprehensive literature review of research on feedback (Shute, 2008). Learning scientists have found that simply indicating the presence of an error (e.g., "error flagging") is less effective than providing feedback that is "elaborated" with specific information on how the learner can improve. When errors are flagged without elaboration, learners can experience uncertainty on how to proceed. The resulting ambiguity can lead to frustration and decreased motivation.

Note that even when suggestions are suboptimal, they may still lead to better visual design. When participating in a critique, a scientist-designer is first prompted to recall design principles, then asked to evaluate both the current visualization—as well as proposed changes—against those guidelines. The critique encourages scientists to spend more time thinking about, discussing, and working on the visualization task, which may lead to improvements, even when feedback is misdirected or incorrect (Bierut, 2006).

*4.1.2 Scientists increased the specificity in both their suggestions and problem identifications, including more references to visual principles as supporting rationale*

For example, when evaluating Figure 4 after the intervention, Participant A expanded their general pre-intervention suggestion ("to pare down to only essential images") by explaining that fewer images could be shown in a larger size so that details within those images would be more legible. Participant A also elaborated on their original suggestion to "restructure and clarify the relationship between the images" by explaining (post-intervention) that the coexisting horizontal and vertical orientations were in visual competition.

BEFORE the intervention, Participant A:
"*I think that the figure could be pared down to only the essential images and restructured to clarify the relationships between the different images.*"
AFTER the intervention, Participant A:
"***Currently, the figure has multiple levels of organization (horizontal and vertical), and it is unclear which level of organization dominates.*** *I think that the figures should be rearranged to make the relationship between the individual images and groups of images clearer. Perhaps not all of the images are necessary to create meaning for the reader.* ***I would suggest using fewer images but making sure that each element of the images used is large enough to be readable***."

Similarly, when evaluating Figure 5 prior to the intervention, Participant B initially made a generic feedback comment ("too complicated") that could be applied to many scientific figures. After the intervention, Participant B made two new suggestions that were more specific: (1) to consolidate two legends into one, and (2) to change the map sequence so that the detailed enlargement follows the smaller overview. The second suggestion was justified by explaining that the new sequence would align the map progression with a left-to-right visual scanning pattern, which is common in Western cultures (Smith & Elias, 2013).

Participant B BEFORE the intervention:
"*Too complicated.*"
Participant B AFTER the intervention:
"*Include the Range, Study site, Present, [and] Not detected in the same legend.*
***Put Africa on the left and the zoomed-in [map] on the right, because it makes sense to move hierarchically from left to right (zoom out → zoom in).***"

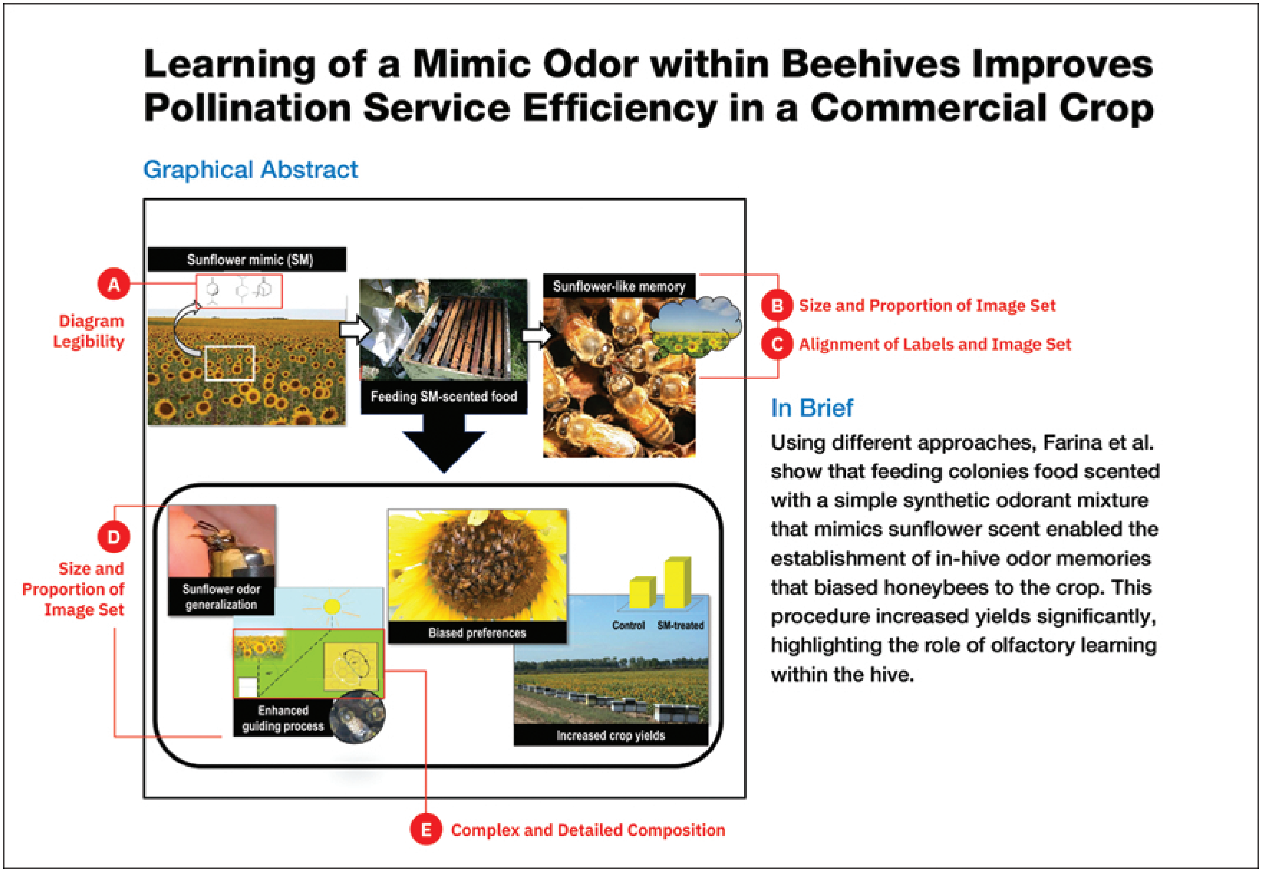


**Figure 4.** A graphical abstract shown to scientists for visual critique. Red annotations have been added to the original to highlight potential issues with visual design. A and E show sub-diagrams with components that are difficult to read. B, C, and D point out images that vary in size, proportion, and alignment, including caption blocks. Overall, the structure of the figure presents a confusing sequence due to the conflict between horizontal elements (the two rows) and the vertical black arrow.
Original figure reproduced with permission from *Current Biology* (doi.org/10.1016/j.cub.2020.08.018)

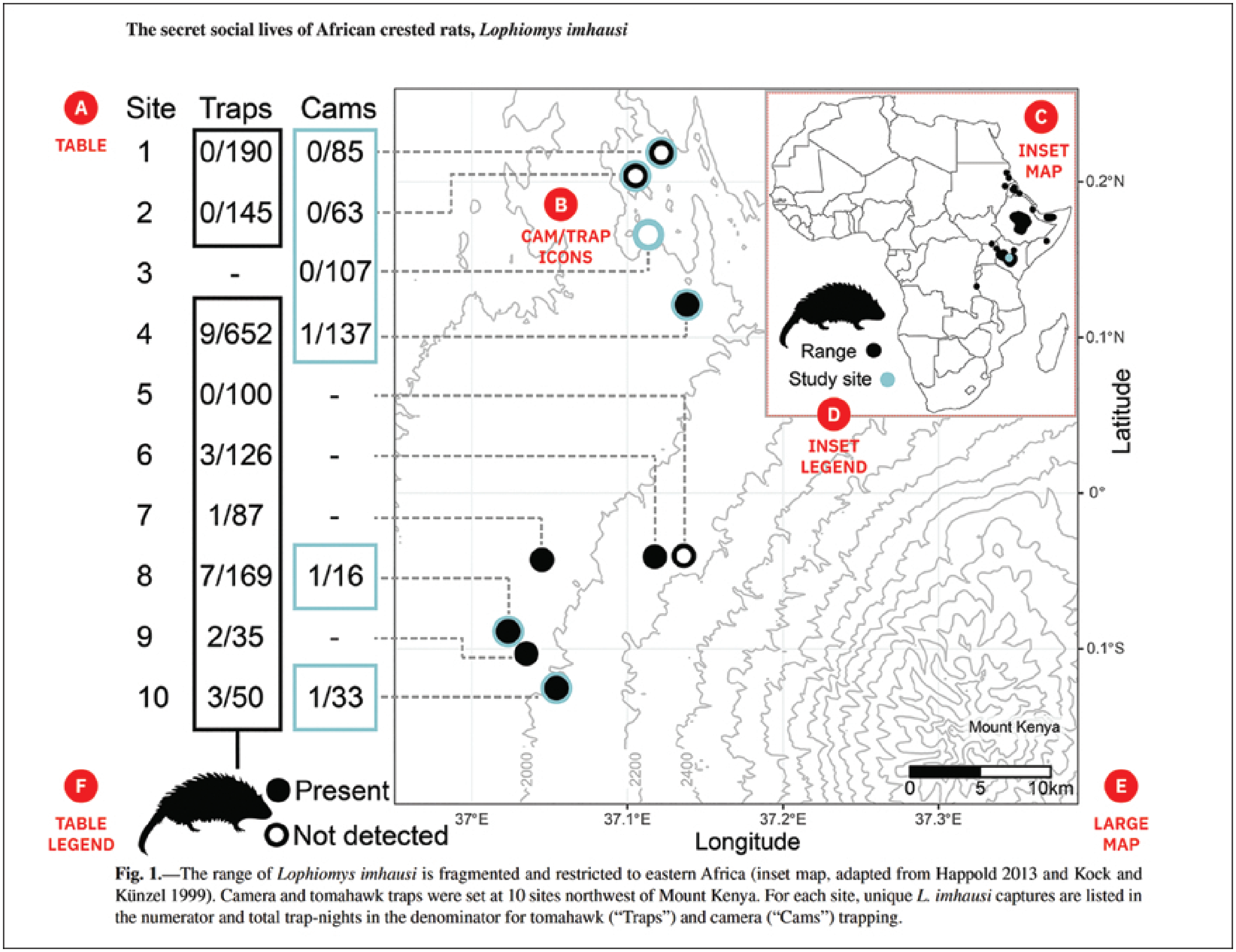


**Figure 5.** A scientific figure shown to participants for visual critique. Red annotations have been added to the original to highlight potential issues with visual design. In A the table is not easily correlated with the map (E). In B and C circular icons are difficult to distinguish. A lack of common landmarks—such as Mount Kenya—between the two maps (C and E) hinder the user from connecting the two spaces. Two competing legends (D and F) provide different meanings for the light blue highlight color (light blue is used for both "study site" and "cams"). Original reproduced with permission from the *Journal of Mammalogy* (doi.org/10.1093/jmammal/gyaa127)

#### *4.1.3 Scientists became more focused on using visual attributes to direct attention to a "key message"*

Many guides on "how to write a scientific paper" already advise authors to limit each figure to communicating a single main idea (Whitesides, 2004). However, it is notable that scientist-participants sought to apply their newly acquired visual design knowledge to achieve communication goals.

For example, when considering Figure 5 (showing the locations of African crested rats) in the pre-intervention condition, Participant A initially offers three suggestions for relatively simple repairs. However, after the intervention, Participant A suggests a more complex repair based on the strategic objective of emphasizing one set of information (where rats were found) over another (how rats were identified).

> Participant A BEFORE the intervention:
> "*I think both maps (the inset map and the larger map) should be of the same type (geographical or topographical). Also the key should be more comprehensive to include all types of open/closed circles of all colors shown in the figure. The authors should consider using percentages instead of raw numbers because the varying denominators make the data very difficult to compare.*"
> Participant A AFTER the intervention:
> "***The figure is busy and it is difficult to tell what the key takeaway is****. I think that the numbers should be presented as percentages, because it is difficult and time-consuming to try to compare the fractions with different denominators.* ***I think that the method by which the rats were identified (traps vs cams) should be de-emphasized if the goal is to communicate the locations in which the rats are found.*** *Also, I would suggest not using the same color scheme in the main figure for traps and cams as in the inset for range and study site, as this overlap is confusing.*"

In the same way, after the critique intervention, Participant C also considers what could or should be the main communication goal of Figure 6: to show how a human wrist could change after an operation. Note that the suggestion (to show a sequence of X-rays "from pre-op to post-op") is also more detailed and ambitious than the pre-intervention recommendations, as the scientist-author would need to create or source new images, not just edit or rearrange existing content.

> Participant C BEFORE the intervention:
> "*The text contains too much information not related to the figure. They can be moved elsewhere. No complaints about the pictures except the small fonts.*
> Participant C AFTER the intervention:
> *The colored illustration can use better contrast as well as bigger font size (scaphoid and lunate). Show the same hand/wrist! It appears that the "torn SL" image shows the right hand and the "normal wrist" shows the left. Simple text can be added to the red arrow to explain the gap between the bones. It is probably helpful to know what the normal separation between the scaphoid and the lunate is so we know that the "torn SL" image shows abnormality. The background information in the text above seems redundant and can be put elsewhere.* ***If the focus of the figure is on pre-op vs post-op, maybe it's better to show successive X-ray images of the lunate/scaphoid gap opening up over time.***"

#### *4.1.4 Scientists increased the number of suggestions that employed visual attributes rather than text editing*

Prior to the intervention, 22% of the suggestions made by scientist-participants recommended revising captions, adding explanatory labels, or using bullet points to clarify a figure. After the intervention, only 6% of the suggestions recommended these text-based revisions.

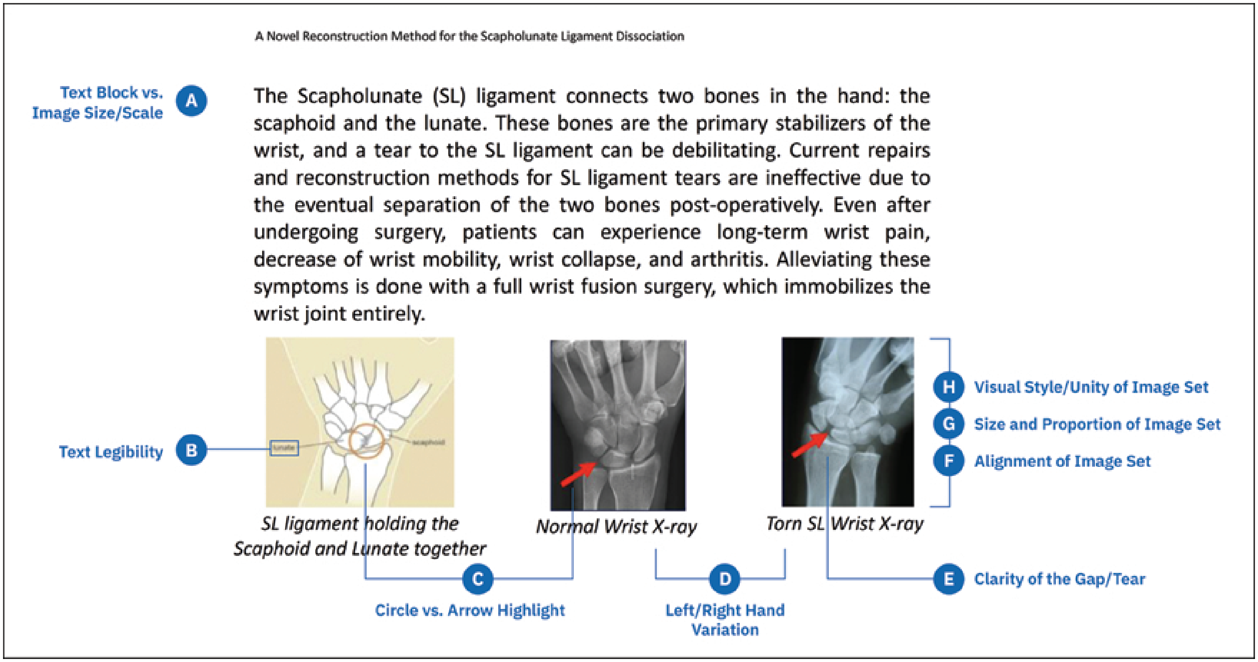


**Figure 6.** An in-progress figure draft from a research poster for a university department symposium shown to study participants for visual critique. Note that blue annotations are not original; we have added them to highlight visual design issues; the red arrows are part of the original figure. In A, size relationships could be improved as the text block is very large relative to the images. Similarly, in E the gap between bones is difficult to see. In B small labels in the illustration are difficult to read. In C graphic highlights are inconsistent, as the first image uses an orange circle while the others have red arrows. In D both a left and right hand are shown, making the location of the gap more difficult to perceive. The alignment (F), size and proportion (G), and visual style (H) of these three images also vary considerably. Reproduced with permissions from the authors

For example, several participants noted that it is difficult to see the differences between the four stages of the molecule shown in Figure 7. Prior to the intervention, text-based suggestions included "providing clear labels for each step," "the description/definition of terms should be clearer," and "revising the caption to more clearly convey why [the listings are] relevant (e.g., why do we care about calculated log(P)?"). After the intervention, visually based suggestions included "the chemical changes from each generation could be highlighted with a different color," "contrast can be used for the drug names (either bold or larger text)," and "convert the numbers on the bottom right of each compound into a graph so that the comparison amongst compounds could be easier."

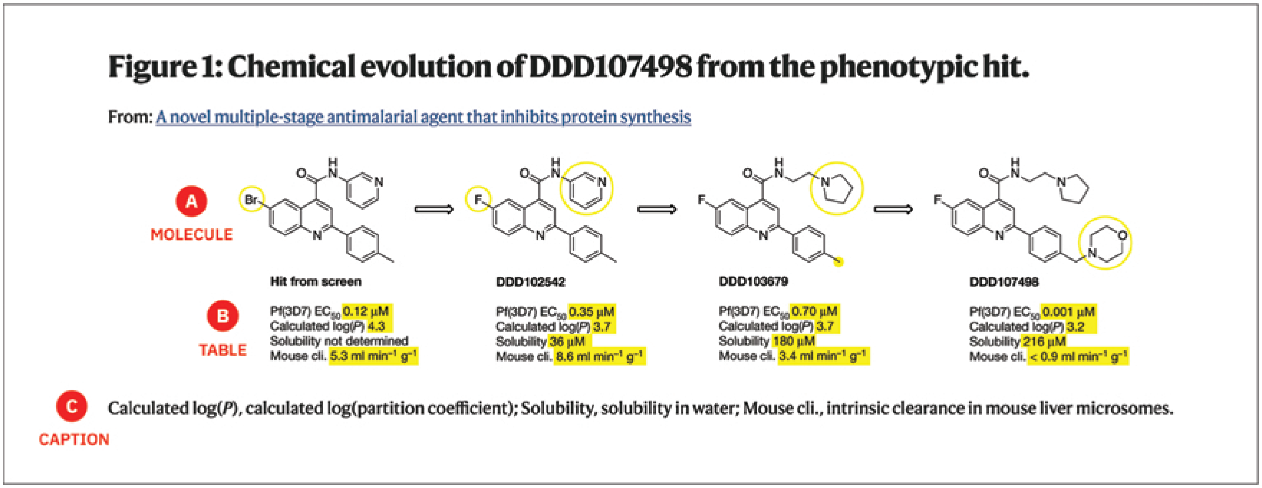


**Figure 7.** A scientific figure shown to study participants for visual critique. Note that red and yellow annotations are not original; we have added them to highlight visual design issues. In A, yellow circles emphasize changes in the molecule that would otherwise be subtle for a casual viewer to detect. In B, yellow bars draw attention to the changing values in the table; this table could be reformatted—or values could be graphed—to make these differences more salient. The text in the caption (C) could be incorporated into the table (B) to avoid redundancy and to consolidate related information. Original reproduced with permission from *Nature* (doi:10.1038/nature14451)

It should be made clear that we fully support suggestions to revise and improve captions, labels, and bullet points. Better writing serves the overall goal of making scientific findings more accessible. However, currently, scientists typically have more knowledge and training in writing than in visual design. Therefore, an increase in understanding and leveraging visual design strategies may have more potential for the improvement of scientific figures.

### *4.1.5 Scientists expect figures to communicate specific kinds of content*

For example, in referring to the graphical abstract shown in Figure 4, Participant D noted, "I find these kinds of figures pretty upsetting because they don't really present any quantitative information and without context just kind of suggest the terminology that the study's going to use." Participant E was also critical, stating, "I actually don't think any pictures are needed, the summary on the right explains all that I need to know" (referring to the accompanying text abstract).

Such an attitude from scientists may be considered natural, given the limited space that most journals allocate for visuals—a restriction that was historically tied to the costs of producing a printed volume. While electronic publication has since eased the financial costs of publishing visuals, creating an effective figure still represents a significant effort for a busy scientist, particularly for a scientist without design training. Therefore, scientists may logically choose to reserve the time-consuming development of visuals for those diagrams, charts, and graphs that serve certain purposes (i.e., that display data and/or replace lengthy text descriptions.)

## 5. Conclusions

### 5.1 Implementing critique in STEM lab groups

The results of this study show that scientists can improve both the quantity and quality of their feedback on visual figures by participating in training that explains visual design principles and critique methodology, including actual practice in a design critique of their own work-in-progress. There are, of course, limitations to this study. The recruited labs were led by STEM faculty who already valued visual design enough to invest the time in training their group. Additionally, the intervention was conducted by an experienced visual designer who was capable of effectively guiding scientists in the acquisition and application of visual knowledge. These conditions and resources may not be available to all research organizations.

Our hope for this intervention was that establishing visual design principles and critique practices would increase both the quantity and quality of visual design feedback within lab groups, leading to a self-sustaining, positive cycle of feedback and improvement—therefore resulting, over the long term, in better scientific figures in individual research groups, and better scientific figures in STEM disciplines. However, we do not know if the gains from critique (or even the practice of visual critique) can be sustained without the continued presence and stimuli of having a visual expert regularly collaborating with the research group. It would be valuable to interview members of these lab groups later and ask them to reflect upon their ability to design and critique scientific figures.

It may be possible to minimize the direct involvement of an in-person design expert by developing tools or resources that support and enhance critique in scientific lab groups, perhaps in conjunction with pre-recorded lectures and/or assigned readings. A number of critique manuals already exist (Lerman & Borstel, 2003; Connor & Irizarry, 2015; Buster & Crawford, 2009), but to our knowledge, none have been customized for specific use by STEM researchers seeking to improve their design of scientific figures.

Fortunately, a large part of critique effectiveness rests not with the design expert/moderator, but with the participants. Researchers in the learning sciences have shown that peer feedback can have significant advantages over expert feedback. Peers may be better able to detect, diagnose, and generate solutions to certain problems, because they have direct experience with the issues at hand (Cho & MacArthur, 2010).

Furthermore, in the research lab, as in the design studio, individuals are often close-knit collaborators who have worked together for several years. They can be highly invested in each other's success and may have developed the social trust and mutual respect that enables the candid sharing of constructive feedback (Schrand & Eliason, 2012).

The organization and structure of a research lab is, in many ways, already well-suited to a regular practice of critique. Often, scientists are already working and reporting as small teams; these groups can begin working collaboratively to review each other's figures in progress (groups can often find and detect more visual errors than an individual working alone). The larger overall research group can also effectively serve as a kind of test audience that can be helpful when evaluating design variations and making key visual decisions. Finally, research groups are already accustomed to brainstorming, developing, and refining scientific ideas and inventions. Our findings suggest that these collaboration practices can also accommodate the iterative cycle of designing visual figures.

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