Department: Visualization Viewpoints
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Close Reading for Visualization Evaluation

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***Abstract*—Visualizations produced by collaborations between artists, scientists, and visualization experts lay claim to being not only more effective in delivering information but also more effective in their abilities to elicit qualities like human connection. However, as prior work in the visualization community has demonstrated, it is difficult to evaluate these claims because characteristics associated with human connection are not easily measured quantitatively. In this Visualization Viewpoints piece, we address this problem in the context of our work to develop methods of evaluating visualizations created by Sculpting Visualization, a multidisciplinary project that incorporates art and design theory and practice into the process of scientific visualization. We present the design and results of a study in which we used close reading, a formal methodology used by humanities scholars, as a way to test reactions and analyses from evaluation participants related to an image created using Sculpting Visualization. In addition to specific suggestions about how to improve future iterations of the visualization, we discuss key findings of the evaluation related to contextual information, visual perspective, and associations that individual viewers brought to bear on their experience with the visualization.**

The visualization community has recognized the benefits of incorporating the arts and artists into its conceptualization and design processes. While this may seem like an obvious match since artists are experts in expressing complex ideas visually, technical and disciplinary barriers have made it difficult for artists and visualization teams to work in concert. Thus, there is a rich history of research into tools and processes to facilitate this type of collaboration.[6,18,19] In the course of our research, we have found that in addition to

Digital Object Identifier 10.1109/MCG.2020.2993889
Date of current version 12 June 2020.

Published by the IEEE Computer Society

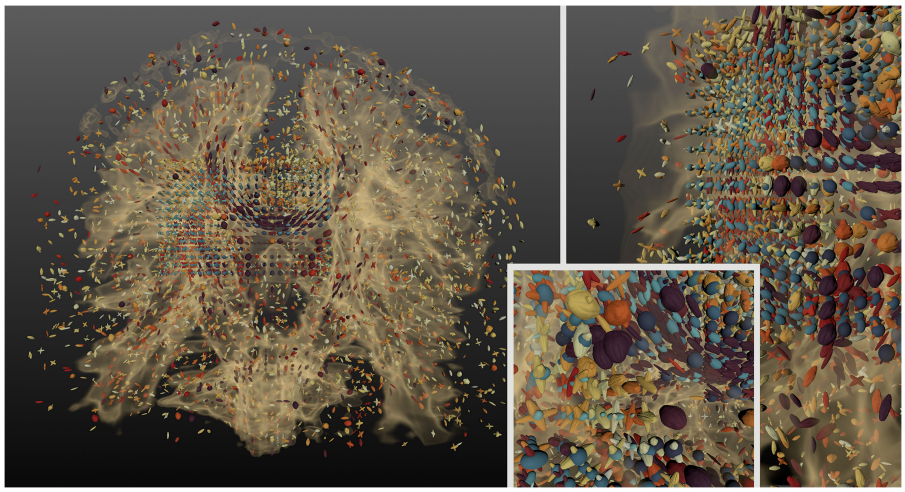


Figure 1. Visualization of neural imaging data created using Sculpting Visualization.[10] Glyphs and colormaps were created using principles from art and design theory that allow for a greater visual vocabulary and more effective data encodings.

technical barriers to entry, the evaluation also poses a conundrum for incorporating the arts into visualization. How do we determine whether or not artistic approaches to visualization add value to match the added time and resources that they require? How do we gauge if these approaches increase not only the informative qualities of visualization, but also those related to quantitatively elusive qualities like human connection, pleasure, enjoyment, and engagement? In our work, eliciting human connection is defined as a visualization's ability to meld its informative intent with the individual experiences, contexts, and reactions of viewers to spark a meaningful internal conversation. As humanities research on climate change visualizations reminds us, "our understandings of visualizations depend on the contextual knowledge, vocabularies, and sociocultural positionings we bring to them."[13] We found that employing close reading as a method for evaluation allowed us to further break down how this internal conversation plays out in reference to specific features of the visualization.

In this piece, we approach these questions from a stance of interdisciplinarity, suggesting that methods from the humanities and the arts can be useful in the interpretation, evaluation, and iteration of visualizations. We present a specific case study in using close reading to evaluate our research team's work, part of a larger project, Sculpting Visualization. Sculpting Visualization is conducted by a multidisciplinary team that includes artists, computer scientists, domain scientists, and humanities researchers; it applies art and design theory and practice to the development of applications, interfaces, tools, and other resources for scientific visualization (see Figure 1). Our most recently developed methodology, artifact-based rendering (ABR) makes it possible for natural, handcrafted, and machine-made objects to be rendered digitally and included in visualizations (see Figure 2).[18] As such, our work makes it possible for traditionally trained artists to create serious, data-driven immersive visualizations while simultaneously expanding the visual vocabulary for visualization, allowing for a wider realm of possibilities for artifacts that can be included in visualizations, including those that are sculpted with artistic principles in mind (see Figure 3).

Figure 2. Our work creates an expanded visual vocabulary by allowing for the incorporation of handcrafted glyphs and a much wider range of formal possibilities into visualization.

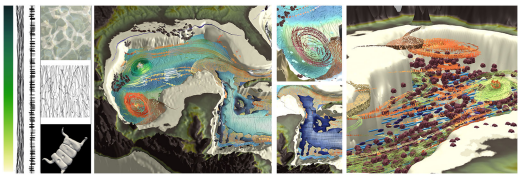


Figure 3. Sculpting Visualization relies on principles from art and design. ABR enables artifacts to be created with qualities like "organic" or "natural" in mind.

In the course of explaining the effectiveness and significance of our work, we usually focus on the informative value of the visualization to scientists. However, we have also made claims that our methods and tools can enhance a visualization's effective possibilities and capacities to engage viewers through human connection. As we continue to develop these tools and to create visualizations based on them, both for scientists and for wider public venues like museums, we need to be able to articulate if and how these artistically driven visualizations promote deeper levels of engagement and connection.

Humanities disciplines center on interpreting and analyzing works of art and culture. In his 2011 *Nature* article about the benefits of incorporating the humanities into climate science research, Mike Hulme argues that the humanities "can reveal how and why people engage or disengage with different representations of climate change" in ways that could benefit positivist disciplines.[15] We suggest that this logic can be applied to visualizations, specifically in the service of evaluation. We aim to experiment with alternative modes of evaluation, including artistic critique and close reading, the method that we discuss here. After a brief overview of prior work in evaluation in visualization and humanities, we will present the design and results of our study, a discussion of how those results might be applied, and future directions for the work.

EVALUATION IN THE VISUALIZATION COMMUNITY

Evaluation is not a new or under-considered problem for the visualization community. The work of Sheelagh Carpendale, among others involved in the BELIV workshop, has made it clear that evaluation is a crucial, yet complicated field for the community to address.[4] In close alignment with the theme of the BELIV workshop, we found that traditional qualitative and quantitative methods of visualization evaluation that relied on task-based assessments like the speed of analysis and emphasized replicability, while crucial in some respects, could not fully capture information about the experiential, associative properties of a visualization. In aiming for replicability, these constraints do not necessarily mirror the "real world" conditions in which individuals encounter visualization, which are not controlled or replicated, though they may have shared outcomes.[24] If we only aim to measure if and how quickly a user can identify a certain feature of a visualization, we miss out on other experiential aspects, like how well it encourages a deep exploration of the data, how its various components work together to create meaning, or as Wang *et al*. recently suggested in the context of data physicalization, how it produces emotional resonance.[25]

Our work also builds on research in the visualization community that draws from an artistic tradition. While we share a similar motivation with Kozik *et al.*[21] to use different values to evaluate visualizations created with artistic principles in mind, our work departs from theirs as we are less interested in evaluating whether or not visualizations conform to aesthetic standards (i.e., aiming to determine whether a visualization is well-liked or considered beautiful by users). Rather, we are interested in determining how specific features of a visualization encourage viewers to partake in an internal dialogue that synthesizes the information presented in the visualization with their own individual experiences and positionings. Our work also differs from theirs in the sense that rather than using more traditional qualitative methods like surveys to evaluate more novel values, we venture a step further by incorporating close reading, a *method* of evaluation that complements the ethos of an artistically driven approach to visualization. The more traditional survey form largely presents study participants with a limited range of potential responses, even if they do involve subjective information. By contrast, close reading, a key humanities method that relies on scaffolded steps of critical analysis and interpretation, allows for a greater range of interpretive possibilities. Close reading enables creativity and analytical agency on the part of

the study respondent. Like deriving glyphs from hand sculptures, close reading opens up myriad, rich possibilities for interpretation of visualizations, and thus, the kind of data that we can collect about them to use in the design iteration process.

ARTS AND HUMANITIES APPROACHES TO VISUALIZATION

The visualization and computing communities have worked most closely with the humanities and literary studies in the subfield of the digital humanities. In this realm, close reading has been most frequently understood in reference to distant reading, a method that treats texts as data that can be analyzed quantitatively to find patterns in literature.[17]

In employing close reading as an evaluation method, our work proposes an inverse of the relationship that characterizes a typical understanding of the digital humanities: ***we don't aim to digitize the humanities, but rather to humanize the digital.*** Following recent lines of inquiry in the visualization community that aim to reconsider the primacy of the general, the replicable, and the quantitative,[22] our work experiments with possibilities for evaluation that are based on attending to visualizations as singular objects whose meaning can change across individuals' interpretations. That is, we don't aim for only "distant readings" of visualizations that create replicable generalizations about their informative qualities based on quantitative task-based measurements. Instead, we look to qualitatively interpret visualizations to determine how individual elements of them produce meaning.

Methods from the arts and humanities have been used in visualization evaluation previously. The most developed body of work in this respect is related to the use of artistic critique and experts in design for visualization iteration and evaluation.[1,16,19,20] However, in these cases, critique was used as part of the design process or by design experts to predict how users would react to specific visualizations. There are also precedents for literary approaches to visualizations that treat them as texts. Literary close reading has been applied in evaluating video games; however, unlike what we propose here, it was used by the creator of the game.[2] Active reading, which relies on annotation, often considered a first step of close reading, has been tested as a method for evaluating the accuracy of visualization tasks.[24]

Our work builds on these uses of reading as a potential mode for engaging with and evaluating visualizations. We turn more explicitly to humanities research–particularly from literary and media studies–that has analyzed data visualizations as objects of study to elucidate the formal, cultural, ethical, and epistemological dimensions of visualization.[7] This work to analyze, deconstruct, and contextualize visualizations has recently begun to emerge in the environmental humanities, as big data and visualization have become key representational forms of climate change. Treating environmental visualizations as cultural objects can generate insights about how "even artifacts without explicit artistic ambitions are rhetorical objects whose formal features are meaning-laden and shape how we comprehend them and incorporate them into our personal and political lives."[13] Visual analyses of climate communication conducted from a humanities perspective have uncovered unintended associations and affects provoked by color and other design choices of climate visualization.[23]

CLOSE READING

We chose to begin our experiments in alternative methods of evaluation with close reading. A vast terrain of research, scholarship, and debate about close reading exists in literary studies, a discussion of which exceeds the parameters of this piece. However, to provide a distillation of close reading as it is most commonly practiced: close reading is paying close attention to a specific text or groupings of texts to interpret their meaning, or, "the mindful, disciplined reading of an object with a view to deeper understanding of its meaning."[3] The interpretation involved in close reading is frequently based on attending to both its content (what the text is "saying") and formal elements (how it is being "said"). This process involves making initial observations about a text's specific features including word choice, syntax, repetition of words, phrases, or sounds, figurative language, shifts in tone, or formal structure.

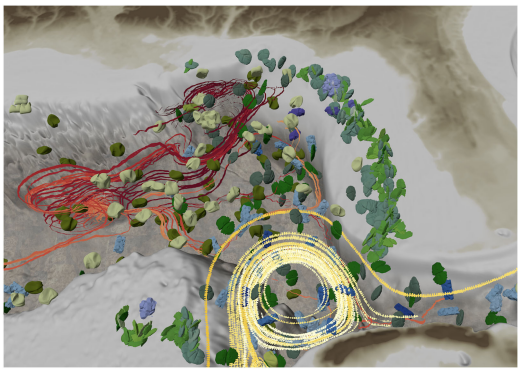


Figure 4. Participants performed a close reading of this visualization created with ABR of biogeochemistry data.[9]

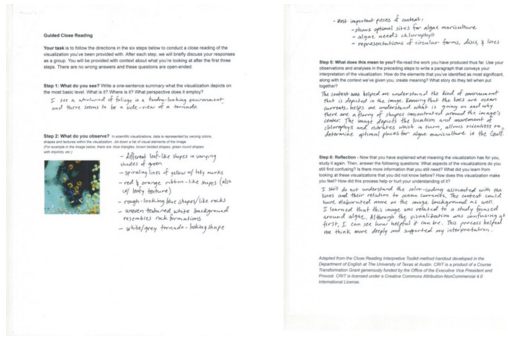


Figure 5. Participants completed a guided close reading worksheet, adapted for visualization.[5] This image shows the first and third of three pages of the worksheet.

Close reading is a widespread, dominant, and ubiquitous practice because it is a teachable skill and process that relies on evidence-based argumentation about a particular text or passage of a text. While as in any discipline, expert-level literary scholars will produce more compelling close readings than a novice, one need not be an expert in a particular literary subject matter in order to conduct or to follow a close reading.

While close reading originated in literary studies, by the late twentieth century scholars across disciplines in the humanities and, in some cases, in the social sciences conducted close readings of a wide variety of texts beyond novels, poems, and other literature: films, visual art, advertisements, and as discussed above, visualizations.[11] The portability of close reading, as it can complement historical analyses, archival research, and qualitative social science research, has made it a key interdisciplinary method across the humanities and social sciences.

While the content and formal features of a visualization are, of course, different from that of a text, close reading as a method can be applied to both. In either case, close reading relies on a series of interpretive moves that apply to visual objects as well textual ones. In the same way that one can observe the formal features of a poem (meter, rhyme scheme, word choice, metaphor, etc.) and interpret them to develop an argument about how they create meaning, one can observe and interpret the formal features of a visualization (color, shape, perspective, aspect ratio, etc.) and interpret them accordingly. As we discuss below in the "Study Design" section, for the purposes of an evaluation study involving nonexperts unfamiliar with both visualization and close reading, we had to make decisions about how to translate and explain the process of close reading. However, as evidenced by the work of humanities scholars who conduct close readings of visualizations as a part of their research, while content, formal vocabularies, and contexts of production and consumption may differ among visualizations and texts, the basic principles of critical analysis (description of the object; observation, identification, and prioritization of its formal features; analysis of how those formal features, along with historical and cultural contexts work together to create meaning; an argument about what that meaning and its implications are) remain constant.[8,12,14,23]

STUDY DESIGN

We conducted a close reading study with 25 undergraduates in an introductory college-level rhetoric and composition course. Students had no known prior training in close reading or visualization and were not given any before this study. A member of the research team visited their class for the day and facilitated a guided close reading of a static image of a visualization created for biogeochemistry research in the Gulf of Mexico (see Figure 4). We chose to give participants a static image for the practicality of the study, as we were more interested in close reading as a method to evaluate visualizations rather than testing technical ease of use. Each participant was given a worksheet to fill out that included instructions for a six-step guided close reading process (see Table 1,

Table 1. Side by side comparison of steps used in close reading a visualization for this study, alongside the CRIT textual close reading steps that they were adapted from Close reading interpretive tool.[5]

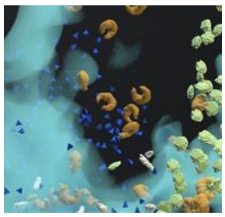
Steps	Textual close reading instruction steps adapted for study	Visualization close reading instruction steps given to participants
Step 1	Paraphrase - Read the passage carefully. In your own words, give a summary of the factual content of the passage—what the text directly states—as it proceeds from beginning to end. What situation is being described here and by whom? What happens in that situation? Respond to this prompt in no more than three complete sentences.	**What do you see?** Write a one-sentence summary of what the visualization depicts on the most basic level. What is it? Where is it? What perspective does it employ?
Step 2	Observe - Read the passage again, this time thinking about what it seeks to accomplish. Then, identify and list any potentially significant features of the passage's language or form—that is, those textual elements that contribute to the passage's overall meaning, purpose, or effect. Your list of observations should include specific examples of various kinds of textual elements, such as descriptive details; word choice; repetition of phrases, sounds, or ideas; imagery or figurative language; syntactical structure; changes in vocabulary, rhythm, or tone; characteristics of the narrative voice or perspective. Note that these observations will have to provide the building blocks for your analysis in Step 4. Respond to this prompt with a list of features.	**What do you observe?** In scientific visualizations, data is represented by varying colors, shapes, and textures within the visualization. Jot down a list of visual elements of the image. *For example, in the image below, there are blue triangles, brown twisted shapes, green round shapes with imprints, etc.* 
Step 3 [Note: See "Study Design" section for the explanation of switch of steps 3 and 4]	Contextualize - Think about contexts for the passage. (Contexts are facts or broader circumstances external to a literary work that are important to its production, reception, or understanding; for instance, literary, biographical, political, or historical information.) From your own knowledge of any relevant contextual facts or circumstances, or from information provided by your instructor, identify and list any potentially significant contexts for the passage—that is, those contextual frames that contribute to the passage's overall meaning, purpose, or effect. Note that these contextualizations may provide additional building blocks for your analysis in Step 4. Respond to this prompt with a list of contexts.	**What's most significant?** Choose four of the observations or associations that you've made above and choose which you think are the most significant. Explain why you think they're significant or any associations that you have with them. [The worksheet included four fill-in the blank style responses to fill in which observations were most important, followed by "This is significant because: _____" for each observation.]
Step 4	Analyze - Review the features and contexts that you identified in Steps 2 and 3 as making potentially significant contributions to the passage's meaning, purpose, or effect. Then, select at least four of these textual elements and/or contextual frames and explain how each is, in fact, significant. These analyses should state clearly and forcefully what each item contributes to your understanding of the passage. Note that these analyses will have to be connected in Step 5, where you will argue for a unified interpretation of the passage as a whole. Respond to this prompt in one to two sentences per feature or context. Each analysis should include the phrase: ". . .is significant because. . ."	**What context might you need to know to better analyze these visualizations?** What questions do you have about what you are looking at? [After responding to this prompt, each participant was handed a separate sheet of paper with the following information: This visualization was created by climate science researchers in 2019. Scientists use these visualizations to determine where macroalgae can grow to identify optimal sites for algae mariculture in the Gulf of Mexico for biofuel production. Algae needs chlorophyll to grow. Nitrates encourage chlorophyll growth. Circular forms represent different types of chlorophyll and the discs represent nitrates. The lines represent ocean currents.]

Table 1. (*Continued*)

Steps	Textual close reading instruction steps adapted for study	Visualization close reading instruction steps given to participants
Step 5	Argue - Reread the work you have produced thus far. Using your observations and analyses in the preceding steps, write one paragraph (at least five sentences) that conveys your interpretation of the passage. State the main thesis of your interpretation—that is, the central claim you are arguing for—and then support that thesis by presenting the evidence you gathered in Steps 1 through 4. Note that your paragraph should integrate and build upon your responses to the Step 4 prompt; your observations and analyses should also add up to an interpretive conclusion about the passage as a whole.	**What does this mean to you?** Reread the work you have produced thus far. Use your observations and analyses in the preceding steps to write a paragraph that conveys your interpretation of the visualization. How do the elements that you've identified as most significant, along with the context we've given you, create meaning? What story do they tell when put together?
Step 6	Reflect - Now that you have advanced an argument, reread the passage again. Then, answer the following questions: What aspects of the passage do you still find confusing? What elements of the passage do your interpretation neglect or set aside? What parts of your argument now appear to you debatable or dubious—that is, what objections could a reasonable person raise to your interpretation of the passage? Keep in mind: no interpretation is perfect or can account for every element of a text.	Now that you have explained what meaning the visualization has for you, study it again. Then, answer the following questions: What aspects of the visualizations do you still find confusing? Is there more information that you still need? What did you learn from looking at these visualizations that you did not know before? How does this visualization make you feel? How did this process help or hurt your understanding of it?

right column). The worksheet began with the following statement: "Your task is to follow the directions in the six steps below to conduct a close reading of the visualization you've been provided with. You will be provided with context about what you're looking at after the first three steps. There are no wrong answers and these questions are open-ended." The facilitator read that statement and then proceeded to guide participants through each step on the worksheet by reading each step aloud and answering students' questions about the process. Participants wrote their answers and completed each step individually before the facilitator prompted the class as a group to move on to the next step. After the third step, participants wrote down what contextual information they might need to better understand the visualization. Participants raised their hands to indicate that they had completed this response and were given a sheet of paper with additional context about the image on it (see Table 1). The facilitator continued guiding them through the final steps by reading each aloud and fielding any questions they had. At the end of the class, the worksheets were collected and students had an open, informal discussion about their close readings, the purpose of the exercise, and about scientific visualization in general.

To engage a nonexpert audience without prior experience in close reading, we adapted the "Close Reading Interpretive Tool" (CRIT), a step by step explanatory process and application for close reading developed by the University of Texas at Austin English Department for instructional use in their courses.[5] Table 1 shows a side by side comparison of the textual close reading steps versus those used for the visualization as a part of the study. As the original CRIT worksheet was intended to help students develop skills in close reading and to be used for assessment purposes, we adapted the language to deemphasize the sense that students were being tested. In the CRIT workflow, analysis follows contextualization, but in step three of our study, participants created analytical statements about the visualization based only on visual features with no consideration of context or explanation of what the visualization was, before receiving contextual information in step four. We chose to conduct the study this way based on lessons gleaned from a

pilot study. With the revised workflow, participants would focus more on visual elements, rather than immediately and only trying to answer scientific questions in a way that might make them feel as if they were being tested.

From a practical standpoint, this proved to be a relatively efficient evaluation method as we were able to garner a large amount of data from 25 people in approximately 40 minutes. Reading all of their responses is also relatively quick; it took about half an hour to read through them carefully. Processing and synthesizing the data proved more time consuming, as open-ended prompts led to varied answers.

RESULTS

In response to Step 1, participants largely wrote a sentence or two describing the shapes in the visualization and tried to describe where they were, the form of the visualization, and its features. Most participants identified the green glyphs, the yellow streamlines, and the red streamlines. Some also mentioned the blue glyphs.

Five participants referred to the visualization as a map or a topographic map. Of the 25 participants, 10 correctly identified the geographic location of the visualization, usually by recognizing and referencing Florida. Two picked up specifically on the presence of rivers. Nine referred to what they perceived to be meteorological features of the visualization related to what many deemed the "background." Clouds, storms, and "weather patterns" were common words used to describe it.

In response to Step 2, participants made lists of the features they noticed in the visualization. In this step and Step 1 collectively, 18 participants referred to the green glyphs as leaves. In this step and Step 1, participants largely described glyphs and streamlines in terms of the materials of which they appeared to be composed. Most participants also described aspects of the visualization using words like twine, rope, feathers, leaves, potato chips, styrofoam, pipe cleaners, seaweed, "chewed gum looking objects," "imprinted puddy," sponges. While some participants refer to them as shapes (coils, spirals, circles), most used the vocabulary of the materials. Two identified shapes as "organic" versus "computer generated" or "artificial."

In response to Step 3, 13 of the 25 participants identified the green glyphs as important, which were most commonly described again as leaves. Most participants also indicated that the red and yellow streamlines were significant. Most participants reasoned that specific features were important based on contrasts between shapes and color, its location in the visualization, how much space it takes up in the visualization, and the frequency that a feature appears in the visualization.

Five participants also remarked on the links between glyph shape/form and movement to identify yellow and red streamlines as significant features, using words like "jagged" and "flow" to describe them. In this step, two participants also noted the ways that "organic" visual qualities of a glyph distinguish from those that seem "computer generated." One remarked that: "The blue shapes are difficult to categorize," which the participant deems significant because "They feel foreign, and computer generated. Makes me more confused about what's happening."

Eleven participants included more metaphorical and affectual associations with specific features of the visualization. Most common were associations between red and yellow streamlines and qualities including "warmth," with one participant remarking on the possibility that these associations in the context of a visualization might suggest a link to climate change. Four participants also interpreted the red and yellow streamlines in reference to specific affectual associations. One noted that "the red rope is very tangled compared to the yellow twine. Seems disorderly and causes a more anxious feeling in the viewer." Another wrote that "red could be seen as the antagonist of the piece. Serves as a contrast to the rest of the work."

In response to Step 4, 13 participants wrote that they needed to know what the image was depicting, representing, or what was happening in it. Twelve noted that they wanted to know the meanings of the shapes and/or colors of the components of the visualization. Four specifically noted wanting to know what its "setting" was. After receiving contextual information, most participants noted in some way that the green glyphs represented chlorophyll; that nitrates encourage algae growth; and that streamlines represent ocean currents.

In response to Step 5, 13 participants asserted the relationship between chlorophyll, nitrates, and currents. Some participants took a problem-solving approach and attempted to guess where the macroalgae would grow. Some participants only reiterated their confusion.

Step 6 was the most open-ended step that prompted the most varied responses. Thirteen participants expressed that they still did not fully understand the visualization, even given context. Some of this confusion, they suggested, could have been remedied by a visual key, in addition to a written one. Confusion also remained about the "background" with some participants suggesting that the space representing the water should be blue in keeping with the conventions of maps. Three participants also expressed a desire to understand the "message" of the visualization.

Two participants expressed confusion with the process without greater understanding. However, four participants expressed that the process helped them better understand the visualization. One participant reflected, "At first I had to interpret the visualization on my own, which made me think and look for context clues. Then after receiving the context, I then could see what other people intended it for. This process made me think and it was sort of fun, trying to figure out what the objects stand for and its significance. Then I created my own story." Another noted, "Though I may not fully understand it, the process helped me to interpret the data better. Although I was confused by the image, the process helped my understanding of it."

DISCUSSION OF RESULTS

As noted above, the frequency with which participants described glyphs based on their materials confirms that Sculpting Visualization's artistically generated artifacts encourage a wide variety of associations in the viewer that allow for a larger, more creative visual vocabulary that is not as concerned with whether a visualization is perceived as "beautiful" or "pretty" but rather, as we discuss above, that it is able to encourage inquiry and spark an internal conversation in the user. With minimal prompting, participants produced a wide range of associations and descriptions of visualization artifacts that aligned with the aim of ABR as a tool when evaluated by an artist to provide a multitude of visual options.[18] Their responses and associations help to put specific words, phrases, and descriptions to artifacts that we have created. And while we have previously evaluated the efficacy of visualizations produced using ABR with scientists,[18] their responses focused on highly specific needs for exploring their data, whereas the responses solicited in the close reading process helped us to understand how a nonexpert interprets a visualization. We received a much wider range of reactions and associations that were more focused on the visualization's individual components, overall aesthetic, and how the two realms come together in a viewers' interpretation.

The main value that we find in these evaluations is in helping to guide future iterations of the visualization. These evaluations can be conducted relatively quickly and easily at any point in the iteration process, from an initial prototype of a visualization produced by a new method to an evaluation of a late-stage product. The open-ended answers do not simply determine whether or not the visualization is successful, but rather, allow us to look at individual answers of interest and determine how specific aspects of the composition that they identified contributed to their interpretation. For example, one participant stated, "The red rope is very tangled compared to the yellow twine. Seems disorderly and causes a more anxious feeling in the viewer." This statement could be incorporated into future iterations of the design of this visualization in honing the contrast between the yellow and red streamlines to either heighten or lessen visual disorder. We found that information of this kind—that is specific to the visualization and that speaks to more general associations that individuals draw between visual form and meaning and is generated wholly by the study participant—has been impossible to glean from evaluative studies run in the past.

WHAT HAPPENS WHEN A SCIENTIFIC VISUALIZATION LEAVES THE LAB?

Our clearest finding was that the context and information presented with the visualization–including labeling, how it's framed, and written description–is crucial to understanding. Without effective context, the visualization means little to its audience. While we provided participants

with a paragraph long summary of the science of the visualization, according to the answers that we received, it would have been clearer with geographic labeling ("Gulf of Mexico") and a visual key. Further, participants also expressed the desire for more context, especially related to design decisions ("why do some shapes look organic and others artificial?"; "why are the chlorophyll and nitrates shaped the way they are?").

Related to the finding above about context, scientific visualization serves very specific scientific questions. However, our evaluation points to the fact that if they are to circulate "beyond the lab," scientific visualizations need to be translated to specific public audiences, with attention to issues of visual association and context. We plan to further develop this problem as a research question in future studies. Some questions that we pursue may be: how do exploratory and explanatory visualization differ in terms of evaluation? What, if anything, do scientists want the public to think, feel, or do in response to visualization? As our results show that some participants specifically noted that close reading enhanced their understanding of the visualization, how could we incorporate close reading into the visualization classroom, a museum setting, or other arenas where it can be used as a tool to encourage greater understanding and analysis? In addition to providing more context, our study also pointed to the fact that participants were eager to understand how the visualization that they were presented with connects to a larger "message." ***This suggests that the task of visualization is not only to present the data, but also to effectively frame it and to connect it to larger scientific and societal problems.***

FUTURE WORK AND CONCLUSIONS

In addition to comparing this method with artistic critique, we plan to replicate this study but with more and better context for participants. We have conducted one additional study with advanced environmental science undergraduates whose responses brought up the question of how to evaluate visualizations that are meant to be interacted with or viewed in VR, prompting another potential avenue for research. We also plan to experiment with the type of context we provide; instead of a descriptive caption, we might, for example, give a poem, personal narrative, work of short fiction, or another visualization as context. We have also considered engaging experts (i.e., professors and/or advanced humanities graduate students) in close readings of visualizations.

In conclusion, even from these early studies, we have found that using close reading as an evaluation method allowed us to better understand how specific qualities in a visualization spark human connection–the meaningful interchange between the aims of a data visualization to communicate information and encourage inquiry and the associations, contexts, and positioning that individual viewers bring to their experience with it. Close reading is a highly useful tool for the evaluation and iteration processes involved in visualization because it can elicit what goes on during this interchange and identify how specific features speak to individual users to create meaning.

Resources

We've made the entire guided close reading for visualization worksheet available for download as an editable template for those who would like to replicate this evaluation method or for instructors who would like to use it as a tool for teaching students how to analyze visualizations at https://www.sculpting-vis.org/index.php/evaluation/.

ACKNOWLEDGMENTS

This work was supported in part by the National Science Foundation (IIS-1704604 IIS-1704904). Brain microstructure applications were supported in part by Dr. Christophe Lenglet at the University of Minnesota and by the National Institutes of Health (P41 EB015894, P30 NS076408). MPAS-O simulations were conducted by Mathew E. Maltrud and Riley X. Brady as part of the Energy Exascale Earth System Model (E3SM) project, funded by the U.S. Department of Energy (DOE), Office of Science, BER with analyses conducted by Phillip Wolfram, MEM, and RXB under ARPA-E Funding Opportunity No. DE-FOA-0001726, MARINER Award 17/CJ000/09/01, Pacific Northwest National Laboratory, prime recipient.

The CRIT method reproduced on the guided close reading worksheet was developed in the Department of English at The University of Texas at Austin by Professors Phillip Barrish, Evan Carton, Coleman Hutchison, and Frank Whigham, and Ph.D. students Sydney Bufkin, Jessica Goudeau, and Jennifer Sapio. CRIT is a product of a Course Transformation Grant generously funded by the Office of the Executive Vice President and Provost.

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