SUPPORTING TEACHERS' CRITICAL READING OF A RELEVANT DATA VISUALIZATION

APOYAR LA LECTURA CRÍTICA DE LOS DOCENTES DE VISUALIZACIONES DE DATOS RELEVANTES

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In this paper we present findings from a design research study of an activity designed to engage teachers in critically reading a relevant data visualization. To help us capture the ways that the teachers were reading the data visualization we created a new framework for reading data visualizations from a critical statistical literacy perspective building from prior research. The two-dimensional framework is designed to capture types of reading (i.e. reading the data, reading between the data, reading beyond the data, and reading behind the data) intersected with layers of reading the word and the world with data (i.e. reading the word, reading the world personally and culturally, and reading the world socio-politically). We found participants engaging in every type and layer of reading data visualizations from our framework. However, they most frequently engaged in reading at the sociopolitical layer.

Keywords: Data Analysis and Statistics, Teacher Educators, Design Experiments.

Choice of Problem

The reading of graphs of data has been often associated with statistical literacy (Gal, 2002), which has been included in the school mathematics curriculum of the U.S. over the past several decades (Scheaffer & Jacobbe, 2014). Past scholarship (i.e., Curcio, 1987; Friel et al., 2001; Shaughnessy, 2007) synthesized different ways that people engage in reading graphs and also shaped curriculum and guided scholarship on people's understanding of reading graphs. However, the ways data is visualized has changed significantly over the past few decades due to technological advances and new forms of media. Wilkerson and Laina (2018) describe data visualizations as those that "use context rich and interactive methods to create narratives and allow users to explore data for themselves" (p. 1). This definition expands beyond traditional graphs to include new forms of data visualization, such as dynamic and interactive spatial displays of data or scrolly-telling, where data visualizations change as a person scrolls down an article on a device. With such advances in how data is visualized and presented to the public, we see a need to revisit old frameworks with new data and lenses to consider the realities of how people encounter data in the world today.

Teachers, who are entrusted to enact the mathematics curriculum that students experience directly (Remillard & Heck, 2014), are at the forefront of curricular shifts such as updating how we teach and learn about data visualizations. As a result, in this study, we focus on a design research study of supporting mathematics teachers' in critically reading data visualizations. Studying mathematics teachers reading of data visualizations is particularly important not just because they can shift the types of experiences students have with statistics, but because they themselves have often had few if any prior experiences learning statistics themselves (Shaughnessy, 2007). Additionally, past work has found that mathematics teachers are not

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confident in their ability to teach the statistics concepts required in their state standards (Lovett & Lee, 2017, 2019). The emergence of data science entering the K-12 curriculum in many states (Drozda et al., 2022) has only increased the demand on mathematics teachers to incorporate data visualization into their curriculum.

In this paper, we study the research question: How do mathematics teachers read a relevant data visualization? To help us capture the ways that the teachers were reading the data visualization, we created a new framework for reading data visualizations from a critical statistical literacy perspective (Author, 2017) building from prior research. We discuss implications for the design of data visualization activities for teacher education. This study addresses the theme of the conference, envisioning the future of mathematics education in times of uncertainty, by considering new ways of engaging in the reading of data visualizations, which is increasingly a crucial practice as a member of democratic societies that have become increasingly dominated by data in our current information age.

Theoretical Framework

Our framework is composed of two dimensions. One dimension is types of reading (i.e. reading, reading between, reading beyond, and reading behind), drawing from past scholarship that focused on people's reading of graphs and supporting graph comprehension (Curcio, 1987; Friel et al., 2001; Shaughnessy, 2007). We found this dimension alone was insufficient to capture the different ways people read data visualizations, as past scholarship only took a disciplinary and objective look at graphs. From our critical statistical literacy perspective, what was missing was a critical epistemological perspective, which more recent literature has considered. Drawing from Lee et al.'s (2021) Call for a Humanistic Stance in Data Science Education, where they put forth three layers of such an education including personal, cultural, and sociopolitical layers, we added a second dimension of layers of reading practices where one layer captures the more technical disciplinary practices that we refer to as reading the word drawing from Paulo Freire's (1970) literacy work and then two more layers that center on reading the world with one layer focusing on personal/community practices and the other is focused on sociopolitical factors. We also liken this perspective to the key aspects of culturally relevant pedagogy, where academic excellence maps to reading the word, cultural competence maps to reading the world with personal/cultural practices, and sociopolitical consciousness maps to reading the world sociopolitical practices (Ladson-Billings, 1995).

To unpack the specific practices of our two-dimensional framework we first drew upon past scholarship on reading graphs (Curcio, 1987; Friel et al., 2001; Shaughnessy, 2007). Curcio (1987) created three types of reading graphs for educators to consider as they formulate tasks and questions aimed at improving students' graph comprehension – reading the data, reading between the data, and reading beyond the data. The descriptions of these can be found in Table 1. Shaughnessy (2007) extended these reading levels to incorporate a fourth level – reading behind the data – to highlight the causes for variation in data represented in graphs and to make connections between the context of the data and the graph. Since then, numerous studies have used the reading levels framework to analyze news stories and student work with graphs, statistical tables, and maps (da Silva et al., 2021; Rubel et al., 2016). There is also important work from statistical literacy on reading in statistics such as considering how data is collected to determine what type of claims are warranted, when common forms of bias are present in the methods and other common methodological issue such as sample size (Bailey & McCulloch,

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2023; Gal, 2002; Utts, 2003). These practices focus on disciplinary practices which we mapped to the reading the word layer of the framework.

Reading the world facilitates an individual's understanding of themselves, their culture, and their community (personal/cultural layer) as well as analyses of power, oppression, and structural inequities (sociopolitical layer; Freire, 1970; Gutstein, 2006). For example, Rubel et al. (2016) discuss how students often try to locate themselves in the data they are investigating. Rubel et al. (2021) extends their previous work by further considering the practices of narrating, formatting, and framing involved in taking critical reads of data visualizations. These practices describe considering the author's message in a data visualization and how they have highlighted certain aspects of the visualization to convey a message. Bailey and McCulloch (2023) also discuss practices such as acknowledging alternate explanations of the data and recognizing gaps in one's knowledge of the context being explored that is needed to interpret the statistical message. Kahn et al., 2022) also went beyond previous work and additionally included the consideration of feeling and emotions in the reading of data visualizations. It is important to note that though we developed categories in our framework that we differentiate we see them as deeply interrelated where expertise consists of coordinating between different types of reading of data visualizations to read the word and the world.

Table 1: Framework for Critically Reading Data Visualizations

Reading Types	Reading the Word Practices	Reading the World Personal/Community Practices	Reading the World Sociopolitical Practices
Reading the data **Extract information from the data (Friel et al., 2001)**	To recognize the components of graphs, the interrelationships among these components, and the effect of these components on the presentation of information in graphs (Friel et al., 2001) To speak the language of specific graphs when reasoning about information displayed in graphical form (Friel et al., 2001)	Looking for oneself in the data (Rubel et al., 2016)	Look for source of data Look for author/affiliation of visualization Questioning why an author has highlighted particular aspects of a graph or left them absent
Reading between the data **Find relationships in the data (Friel et al., 2001)**	To understand the relationships among a table, a graph, and the data being analyzed (Friel et al., 2001). Finding relationships or trends in the data visualized Recognizing the types of relationships (correlational or causal) can be claimed based on the data collection methods (Utts, 2003)	Making sense of the data visualization in relation to one's own personal experiences	Questioning how and why the author has highlighted particular relationships in the graph (Rubel et al. 2021)

	Identifying the relationships highlighted in the graph (Framing; Rubel et al. 2021)		
Reading beyond the data **Move beyond the data (Friel et al., 2001) to consider interpretations, inferences, and predictions/ extrapolations**	Interpreting information in a graph and answering questions about it (Shaughnessy, 2007) Predicting outcomes based on reasonable claims made from the graph (Shaughnessy, 2007) Making claims/inferences based on patterns and trends in the data to a population beyond what is represented in the data	Making predictions/ claims/ inferences from the data visualizations by drawing upon one's own personal experiences Recognition of one's bias and its impact on interpreting data (Bailey & McCulloch, 2023; Author, 2017) Acknowledging possible Alternate Explanations (Bailey & McCulloch, 2023) Drawing upon personal experiences facing inequities in the interpretation of the data visualization (Bailey & McCulloch, 2023) Connecting to one's feelings/emotions related to the data visualization (Kahn et al. 2022)	Making connections to alternate explanations of others (Bailey & McCulloch, 2023) Recognizing the story, the author is trying to tell with this data (Rubel, 2021) Questioning the author's motives for telling this story (Rubel et al., 2021) Identifying structural inequities at play in the interpretation of the data visualization (Bailey & McCulloch, 2023)
Reading behind the data **Making connections between the context and the data (Shaughnessy, 2007)**	Looking for possible causes of variation (Shaughnessy, 2007), based on the context being measured and the way the data was collected Looking for relationships between variables based on the context Recognizing appropriate graphs for a given data set and its context (Shaughnessy, 2007) Recognizing Appropriate Statistics & Appropriate Representations (Bailey & McCulloch, in 2023)	Using your knowledge of the context of the data to interpret why particular patterns exist in data as well as data generation process Using knowledge of one's community to interpret why particular patterns exist in the data to question aspects of the data generations process Questioning the investigative process undertaken based on personal experiences/identity Recognition of the gaps in one's knowledge of the context needed to interpret the statistical message. (Bailey & McCulloch, 2023)	Questioning sample size and methods (Bailey & McCulloch, 2023) and their impacts on inferences (i.e. practical significance vs. statistical significant; effect vs. no effect) (Utts, 2003) Recognizing when common sources of bias are present in the data collection (Utts, 2003) Recognizing and questioning the source of the data including what is quantified and how it was measured (Rubel et al., 2021; Author, 2017)

Mode of Inquiry

Research Design

This qualitative study is part of a larger design-based research project (Bakker, 2018; Cobb et al., 2003) studying mathematics teacher's development of critical statistical literacies for doing and teaching statistics. The work reported here is our fourth iteration of this framework. The seven participants in our study are high school math teachers recruited from a school district in the southeastern U.S. One of our participants was a district administrator. Six participants identified as a woman, and one identified as a man. Five participants identified as Black or African American, and two identified as white. The teachers' years of experience include: two people with 4-7 years of experience; one person with 8-10 years of experience; and four people with 16+ years of experience.

Design Activity

The activity the participants engaged in was a modified notice and wonder activity on a data visualization that was published by the North Carolina Department of Public Instruction (see Figure 1).

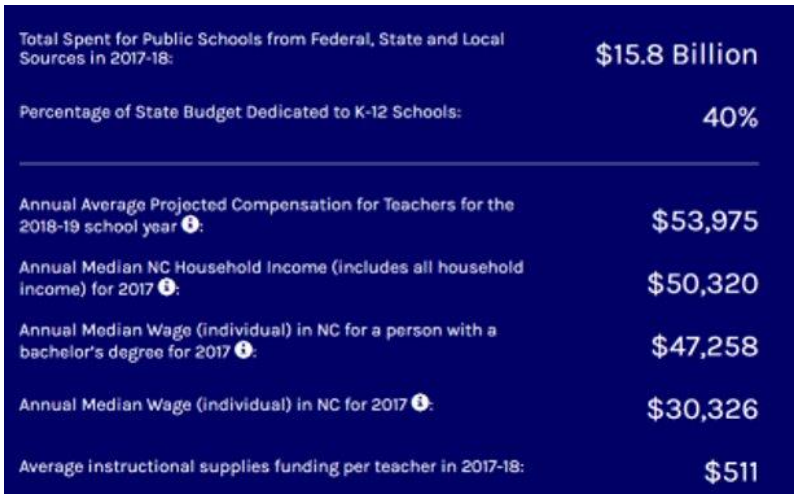

Figure 1: Data visualization published by the North Carolina Department of Public Instruction.

Data Collection and Procedure

Data sources included video recordings of the professional development session, daily written reflections by participants, and ongoing work samples. This comprehensive approach allowed us to capture the nuances and variations in how teachers engage with and interpret data visualizations. The data was collected over a two-week period of the professional development during the summer of 2023. This pilot study focuses on the first 15 minutes of a single introductory activity where the participants are given three questions to consider about a data visualization (see Figure 1): What do you notice? What do you wonder? How does this impact your community? Three members of the research team were present and helped facilitate the professional development and took on a researcher/participant role during the activity.

Analysis

Participant and researcher utterances during the session were coded based on the critical reading data visualizations framework outlined in Table 1.. Three of the authors independently coded the responses, and a comparison was conducted. Differences in coding were discussed until the coders reached 100% agreement. This rigorous coding process enhances the trustworthiness and dependability of our analysis, providing a solid foundation for understanding the diverse ways in which teachers read and interpret data visualizations (Lincoln & Guba, 1985). After coding, we then looked at the frequency of each reading type and layer represented in the data. We identified the patterns in the frequencies for further exploration. We arrived at our findings by looking at themes in the data analysis across reading type, layer, and participant. Once we identified patterns across the themes to develop our findings, described in further detail below.

Findings

We identified two main findings that answer our research question: How do mathematics teachers read a relevant data visualization? In our first finding, we discovered that teachers exhibited engagement across all reading types, with a noticeable emphasis on reading behind the data. Additionally, our analysis revealed that teachers engaged with all three layers of reading, with a predominant focus on the sociopolitical layer. For our second finding, we noticed that different participants engaged in different frequencies.

Table 2 demonstrates the ways teachers engaged with the reading types and layers. Some reading types were taken up less often. For example, reading between the data was underrepresented at the word and personal layers, and no teachers engaged in the reading beyond the data at the word layer.

Table 2: Counts and Precents of Code Occurrences for Each Dimension of the Framework for Reading Data Visualization

	Reading The data	Reading Between the Data	Reading Beyond the Data	Reading Behind the Data	Row Total
Word	9 (16%)	1 (2%)	0 (0%)	3 (5%)	13 (23%)
Personal	1 (2%)	1 (2%)	5 (9%)	5 (9%)	12 (21%)
Sociopolitical	3 (5%)	9 (16%)	10 (18%)	10 (18%)	32 (56%)
Column Total	13 (23%)	11 (19%)	15 (26%)	18 (32%)	57 (100%)

Note: *Percentage values have been rounded to the nearest whole number for clarity and ease of interpretation. The values in parentheses are the counts of each code's occurrence. All percentages are out of the total of 57 occurrences.*

In analyzing the various reading types, regardless of the layer (considering one dimension of our framework), we observed that teachers notably engaged in reading behind the data (18/57; 32%), surpassing the percentages of other reading types such as reading the data (13/57; 23%), reading between the data (11/57; 19%), and reading beyond the data (15/57; 26%). For example, Leona's statement, "you see that important. It's also the vocabulary of median and average because if the community doesn't understand the differences," serves as one instance of reading behind data (from sociopolitical perspective) and that reflects her acknowledgment of the

significance of statistical terminology and the importance of understanding small differences in data analysis. By emphasizing the need for clarity and comprehension among community, she is making a connection between the data and its relevance to the community's knowledge and understanding in a way that it is important for everyone in the community to understand the numbers, so they know how that affects them.

In examining the different layers, irrespective of the reading types (considering the alternate dimension of our framework), we found that teachers engaged in reading the data visualization in sociopolitical ways more than any other layer (32/57; 56% overall), compared to the personal layer (12/57; 21%) and the word layer (13/57; 23%). The reading practices in the sociopolitical layer focus on considering the sociocultural context of the data visualization, which the teachers have firsthand experience and background knowledge of. To illustrate this, consider the following statement from Nancy where she questions the relationships the author of the data visualization is highlight, “But glossing over the fact that we have the small print that says average and then, yeah, median and you're wanting me to compare those two.” Nancy goes on to read the data in a sociopolitical way combining her knowledge of the content with her knowledge of her community to point out that this approach is taking advantage of a common misunderstanding of the differences of means and medians and how the shape of a distribution impacts them, “they say the middle income the middle of this and they don't realize that, that middle is usually the median because we know the distribution is not going to be a symmetric or roughly symmetric right.” Teachers also read beyond the data unpacking the story they thought the author of the data visualization was trying to make and questioning the authors motives. For example, Anna stated, “I think this is designed to show that teachers are making more than most North Carolina incomes.” Some participants also began to make connections between the data visualization they were reading and how they could use it in their own teaching. For example, Melody said, "So I would have used this as a perfect example to my students of how we can make statistics say anything we want," where she is connecting issues of the story being presented how she could use this in her teaching.

We also found that the teachers engaged in reading the data visualization in different ways. Three of the teachers did not engage in verbally describing their reading of the data visualization throughout the fifteen-minute activity. Interestingly, these were the teachers with the least prior teaching experience in the group, though all three had at least four years of prior experience so they were by no means novices. Of the five teachers that did verbalize their reading of the data visualization, three out of the five used sociopolitical more than any other reading type. Table 3 provides a breakdown of each participant’s reading type and layer.

Table 3 Instances of teacher engagement with data visualization activity

		Nancy	Anna	Leona	Natalie	Melody
Reading the Word	Reading the data	2	3	2	2	0
	Reading Between the data	1	0	0	0	0
	Reading Beyond the data	0	0	0	0	0
	Reading Behind the Data	1	0	0	1	1
	Reading the data	1	0	0	0	0
	Reading Between the data	1	0	0	0	0

Reading the World Personal	Reading Beyond the data	2	0	1	1	1
	Reading Behind the Data	3	0	0	1	1
Reading the World Sociopolitical	Reading the data	1	1	0	1	0
	Reading Between the data	3	4	0	2	0
	Reading Beyond the data	2	3	1	2	2
	Reading Behind the data	0	0	3	2	5

Note. *The columns in this table exclusively represent data for teachers who actively engaged in verbal communication during the activity. There were also three teachers who did not engage in verbal discourse during the specified period.*

Out of all the participants, Nancy used the most variety of reading types throughout the entire activity. Nancy's engagement is significant because she engaged in almost every type of reading at every layer, which was not typically as evidenced in Table 2. For example, she was the only participant that engaged in reading the data and reading between the data at the personal layer evidenced in her statement:

> That's the question, does the data represent you? So you subscribe to an identity or something of that nature and but when you look for the data on that identity or whatever it is that are you representing it in that, like does it represent you, It's supposed to represent population or something like that.

Nancy's ability to clearly verbalize her reading of the data visualization was found across the activity and contributed to why so many of her utterances were coded from our framework. This also points to a limitation of our study in that we don't know how the participants who were not as good at communicating their reading of the graph or chose not to communicate at all were engaged in reading the data visualization. This has implications for our design and pedagogy, which we discuss in the next section.

Conclusions and Implications

In this study we sought to explore how mathematics teachers read a relevant data visualization. Drawing from data collected from a larger design research project, we were able to begin to investigate our question and further refine a framework for reading data visualizations. Our framework allowed us to find interesting patterns in the video data we analyzed from the first 15 minutes of a design activity where teachers were engaged in a modified notice and wonder activity with a data visualization we specifically selected because it's sociopolitical relevance to the teachers in our study. One finding was that the teachers engaged in reading both the word and the world in many different ways and in particular heavily engaged in sociopolitical readings of the world through the data visualization. This finding has implications for future design in that we hypothesize the reason for the participants' reading predominantly through the sociopolitical layer was because of the relevance of the data visualization itself. The teachers demonstrated a desire to critically examine data beyond its surface level and show interest in uncovering underlying patterns, causes of variation, identifying biases in data collection methods, and understanding contextual factors.

Another finding from this study was that the teachers engaged in reading the data visualization in different ways. Of particular concern for us was that three participants did not

engage in verbalizing their reading of the data visualization. As a contextual note this activity did occur early on in our larger study while we were working on building community amongst the participants and the participants that did not engage in this activity did so in future activities. However, moving forward, we see it as important to consider how to engage more of the participants in the discussion. We also noticed related to this that finding that of the five teachers engaged in the activity – four had 16+ years of experience. The people with the least experience engaged the least. This points to possible power dynamics that might be at play in the discourse, which was beyond the scope of our analysis, but we believe should be considered in future work.

As data visualizations have become increasingly common in the media today, we see an increased need for teachers to engage in such data visualization activities and to translate them into meaningful experiences for their students as well. Furthermore, we believe our framework can be useful in helping research not only design activities in the future but to analyze the ways in which people engage in reading data visualizations.

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