Data Visualizations: An Integrative Literature Review of Empirical Studies Across Disciplines

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Abstract – This paper addresses the increasing importance of information literacy, especially visual communication and data visualizations. We use visualizations here to mean the visual depictions of data via charts, graphs, and other forms. We focus on data visualizations because they are typically the first thing that draws the reader's attention.

Our study updates the results of a previous literature review on data visualizations [6] that reported on 25 empirical studies that asked participants about data visualizations in health and medical information contexts. By updating this integrative literature review with data from the last five years (2017-2021), our goal is to examine changes in empirical research on data visualizations across disciplines. This analysis of 32 empirical studies found that pictographs, icon arrays, and bar charts remain effective choices for data visualizations with diverse users. However, the studies also point to an ongoing need to conduct research with more contextualized research questions and a focus on interactive displays, issues of numeracy, and a closer look at risk. More so than scholars in other disciplines, TPC scholars are uniquely positioned to focus on context with an eye toward generalizable approaches, which are much needed in research communicating complex health information through data visualizations.

Index Terms - Data visualizations, health communication, infodemic, technical professional communication.

INTRODUCTION

The scale and variety of data has posed new analytic challenges on data visualizations [1]. Issues and challenges of data visualization intersect with what the World Health Organization has called an infodemic, which "is too much information including false or misleading information in digital and physical environments during a disease outbreak" [2].

Data visualizations in health and medical communication remain an important feature for communicating complex information that is directly tied to the potential to reduce disease and promote health and healthy behaviors. But behaviors cannot change unless patients and caregivers understand the information being provided. Moreover, as one study [3] pointed out, the comprehension of visualizations has become an issue of equity tied to policy. In light of the infodemic from Covid-19, the need to be able to read information, especially visual communication and data visualizations, is more pressing [4] – [5]. We use visualizations here to mean the visual depictions of data via charts, graphs, and other forms, and we focus on data visualizations because they are typically the first thing that draws the reader's attention [6]. As such, it becomes important for technical and professional communication (TPC) scholars to understand the landscape of current research about data visualizations.

Previous research in TPC [6] reported on 25 empirical studies from across disciplines that focused on health and medical contexts. The study suggested that there were emerging practices to convey complex health and medical information to diverse audiences effectively. Those practices included the use of pictographs, icon arrays, and simple bar charts for conveying information because those visualization types seem to hold promise for comprehension by users. In addition, the literature suggested that keeping visualizations simple with care in design helped users understand the information presented. Outside of this essay in TPC, the last five years have brought a series of review essays in other disciplines.

The review essays [7] – [8] align with some of the previous findings about design and visualization [6]. However, other recent review essays [9] – [11] claim that as of yet there are no best practices for visualizations and more research is needed. A study [3] moves to claim that dot charts are the most effective type of visualization, though the claim is not based on empirical research findings but rather their interpretation of dot charts and the existing literature. In short, the interdisciplinary landscape of data visualizations in health settings is still murky, which opens a space for TPC scholars to fill. The previous research [6] ended their review with a call for TPC researchers to move more deliberately into this space to conduct empirical research on data visualizations and other visual communication features.

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Over the last five years in TPC, there has been a slight increase in data visualization research. In 2020, there was a special journal issue [12] that contained seven short pieces about data visualizations, yet none were empirical studies that tested visualizations with actual users. Empirical scholarship on data visualizations in TPC remains limited. One study [4] asked users to evaluate the visual design of infographics, but the study's small sample size (n=12) lacked generalizable results. Another group [13] conducted a larger study, using a convenience sample of 329 undergraduate students, gauged reactions to deceptive visualization titles and graph construction, and offered suggestions of ethical data visualization teaching strategies. However, with a primary focus on deception in data visualizations, they circumvented larger concerns such as assessing the users' comprehension of the visualization itself. Moving toward comprehension accuracy, researchers [14] asked 122 contract experts to examine diagrams (flowcharts, swimlanes, and timelines) and icons, but this work was limited from an empirical standpoint because all of the participants were writing experts. As of yet, TPC has no research that examines user response to data visualizations in regard to comprehensive and ease of use in health and medical settings.

Thus, we return to the literature to see what has changed in the empirical interdisciplinary space and move to update the previous study [6]. By producing an updated integrative literature review with data from the years from 2017-2021, our goal is to examine changes in empirical research on data visualizations across disciplines and to determine what, if anything, has changed in the last five years. Since TPC is devoid of research, this study will give TPC scholars working in the visual communication and data visualization space a guide on current trends in effective design of data visualizations. The persistent review across bodies of literature will enable TPC to keep abreast of research that can aid in complex information design for diverse audiences and purposes.

METHODS FOR LOCATING LITERATURE

We picked up the literature review where previous research [6] left off, which meant we limited our search to publication years of 2017-2021. We then followed the same process the previous study [6] outlined to locate and select their literature. Our review was limited to empirical studies that tested visualizations with actual users and focused on communicating information to patients, caregivers, and related individuals who need the information to make decisions.

In addition, we will follow the previous study [6] to search the three major databases (PubMed, Scopus, and Web of Science) for medicine, science, nursing, and the allied health science fields, as well as psychology. We also included a search of IEEE Explore and the ACM databases. We manually reviewed the major journals in TPC: *IEEE Transactions on Professional Communication*, *Journal of Business and Technical Communication*, *Journal of Technical Writing and Communication*, *Technical Communication*, and *Technical Communication Quarterly*. Unlike the rigid review essay format of many science disciplines, our approach used a combination of keywords that helped to systematically limit and expand search parameters. For example, in the original PubMed search for health communication and data visualizations there were 93 articles, but upon review of those, only 4 remained for inclusion in the review.

We used a variety of terms since different disciplines call visualizations different things such as visual aids or the specific type of visual. We also used a combination of health communication, risk communication, graphic communication, and different forms of literacy. Thus, this method does have the limitation that there could be studies that we missed, however, this more qualitative approach to different keyword combinations likely yielded more results than other searching alternatives. In what follows, we examined 32 empirical based articles, and we summarize the findings in the next section

SUMMARY FINDINGS FROM THE LITERATURE

The studies included in this review fall into six major categories: comparison studies, graphs, pictograms and icons, interactive, infographics, and other. A brief overview of the category of main findings are discussed for each category.

I. Comparison studies

Of the 32 studies in the review, 15 focused on some sort of comparison between types of data visualizations. In each case, the goal of the study was to determine if there was a type of visualization that patients (or others) understood better than other types of visualizations. See Table 1.

TABLE 1. RESEARCH COMPARING VISUALIZATION TYPES

Author	Type of visual	Major finding
[15]	compares 41 different types of visualizations	bar, line, pie, bubble, and scatter were easier to read than tree, parallel coordinates, sunbursts, heat maps, box plot, and Sankey graphs
[16]	numerical, graphical, and combined numerical graphical	visualizations with both numbers (as context) and graphs were more effective at helping users understand the risk of accumulating cases of Covid

[17]	tables, bar graphs, and icon arrays	no difference in display format on behavioral intentions
[18]	bar, pie, and temporal area	personalized risk estimates with patients and clinicians; preferred pie charts with contextual information
[19]	bar, line, and pictograph	no overall preference; however, patients slightly preferred pictographs over graphs (bars and lines) and clinicians preferred bar graphs
[20]	stacked bar, clustered bar, linear heatmap, and radial heatmap	clinicians preferred heatmaps even though they are more difficult to interpret
[21]	heat map, dot map, and picto-trendline (which was a form of a bar)	preferred heat maps and picto-trendlines; heat maps increased some aspects of understanding (in this case risk of contracting flu)
[22]	bar, two versions of icon pictographs, and qualitative scale	no evidence of differences though the study was measuring the intervention combined with the visual rather than just the visuals itself
[23]	text-only, text-visual analogy, text-numbers, and text-graph	preferred visual analogies, which are form of a circle chart
[24]	bar and pictographs	upright bar charts reduce cognitive processing
[25]	tables versus graphs (three types of slider graphs)	preferred color block graphs over tables
[26]	tables and text	tables (fact boxes) are more engaging
[27]	visuals (graphic representation and conceptual illustrations)	participant risk perceptions unchanged after adding visuals
[28]	visuals and text	higher and incorrect estimates of risks with text only; personalized decision aids need careful construction of how information should be delivered
[29]	photo versus infographic	not conclusive but the social media environment study offers potential for future research

II. Pictograms or icon displays

Five studies focused solely on different types of pictographs or icon displays. See Table 2.

TABLE 2. PICTOGRAMS AND ICONS

Author	Major Finding
[30]	no conclusive evidence that the type of pictograph makes a difference
[31]	both patients and clinicians agreed that pictographs accompanied by text improves understanding
[32]	found pictographs increases probability of comprehension though the researchers did not study actual comprehension
[33]	symbolic icons may be most effective for health effects not easily visualized; iconic or indexical icons may be more effective for health effects attributable to specific body parts or symptoms
[34]	animation does not help with pictographs and difficulty persists for patients in understanding pictographs of numerical information

III. Graphs

Different types of bar graphs were studied to begin to expand on the general findings that bar graphs are a strong type of visual that leads to understanding of complex information. See Table 3.

TABLE 3. GRAPHS

Author	Major Findings
[35]	clock, pie charts, and bar graphs were preferred but tables were more

	understandable, particularly by older adults
[36]	no finding specific to the graph format, but the addition of text increased understanding of the information
[37]	dot graphs may improve comprehension, but readers prefer bar graphs over tables and dot graphs
[38]	composite bar graphs showed stronger results than other types of bars

IV. Interactivity

Here interactivity means an online interface that is moving toward personalized health information. A study [39] found positive results of interactivity with getting patients to understand the implications of their BMI. They found, "Increased interactivity of data visualization led to less defensive responses toward the obesity website" (p. 1762). In addition, research [40] provides evidence that a high level of modality interactivity in data visualization can reinforce its effect on persuasion outcomes. The results show that "among lower BMI individuals (below a z-score of −.40), highly interactive data visualization significantly enhanced their cognitive absorption" (p. 1715). These two studies, with overlaps in the authorship team, suggest that interactivity can improve patient outcomes. These types of studies need to be expanded to other disease domains.

V. Infographics

Studies about infographics were more about the evidence and source rather than visualizations but the findings are notable in a beginning step in understanding audience for the design of the information.

Research [41] looked at quality of evidence represented rather than the actual visualization, but this is important for scholars to understand the approach to incorporating evidence effectively when designing information graphics. In two blinded, randomized, controlled, online experiments, U.S. participants (n=2140) "were shown one of several versions of an infographic illustrating the effectiveness of eye protection in reducing COVID-19 transmission." Even though they manipulated the infographic (removal of the icon array), findings did not show a statistically significant difference to participants' self-reported understanding of the information.

Another study [15] provided participants (n=20) with 54 data visualizations to test if users are easily able to use and understand the information. The results showed bar, pie, bubble, line, and scatter charts, which are relatively simple in design, were easier to read, while more complex visualizations including tree, parallel coordinate, sunburst, heat map, box plot and Sankey graphs were difficult to understand.

This study [42] looked at comprehension specifically, but only in the moment, so they were actually looking at readability and understanding, not comprehension. Additionally, the pictograms were images that may appear in something more like an infographic. Participants included 101 pharmacy students in Phase 1 and 67 in Phase 2. Results determined that in Phase 1, 4 pictograms met the 67% threshold for comprehension.

VI. Other

The three studies we have placed in this category align with the other studies in the review in that they all focus on trying to understand how users approach information.

Research [43] examined which factors of data visualizations drive attention and trust in rural populations. The researchers used semi-structured interviews and discovered that decisions were framed or driven by personal experience.

Another study [44] performed a qualitative analysis that focused on creating a theoretical framework for how to approach numeracy in patient materials. Thirty participants were interviewed about numeracy regarding self-care in relation to heart failure. The study [44] concluded that communicating health is complex and more attention should be paid to numeracy specifically from a patient's perspective.

Finally, this study [45] looked at the impact of numeracy on information design and found that higher numeracy led to more understanding of information. The researchers used a one-time, online survey that assessed numeracy and risk perceptions including "feelings of risk" and a numerical estimate.

WHAT DOES THE LITERATURE TELL SCHOLARS ABOUT DATA VISUALIZATIONS

Much like the findings of Melonçon and Warner [6], the results of this updated integrative literature review will not be surprising to many TPC scholars. Even though research on the best approaches to visualize data in complex communication situations such as health remains inconclusive, we can make some initial claims that can direct TPC and other disciplines to approaches on data visualizations.

I. *More research and different kinds of research are needed*

Five years later, we had assumed that there would be substantially more studies looking at data visualizations. Using the same approach to surveying the literature, we were surprised to find 32 studies compared to 25 in the previous review. Even with adding in the seven reviews of reviews (which had only a single study surveyed in two of the reviews), we felt that there should be more research

because of the importance of data visualizations to communicating complex information. Thus, the first thing that the literature tells us about data visualizations is that there is still much room for robust, humanistic research studies like those often done by TPC scholars. Much like Melonçon and Warner [6] suggested in 2017, we also suggest that we need more appropriate research questions. In fact, in reading the studies from our review alongside the studies and findings from the previous research [6], a distinguishing characteristic of the research in general is that it is more sophisticated, but we would argue that is not necessarily a good thing. By sophisticated, the questions, inquiries, and approaches to research study design focus on more complex or nuanced questions. For example, [15] wanted to determine how well users understood roughly 40 different visualizations so they set up a qualitative study that began with asking users (who were students) if they understood the visualization. If they did, users were then asked to perform specific tasks to determine if indeed they understood the visualization. However, while this study would feel familiar to those in TPC, the basic premise of the study and approach to interacting with the visualizations was de-contextualized from an actual scenario of use that the findings seem less than conclusive. Another study [43] shows promise in the way it approached trying to understand rural patients, which underscores a pressing need for research focused on more diverse populations. None of the studies specifically approached inclusive sampling to ensure strong representation of under-represented minorities in health research.

II. Pictographs and icon arrays remain a good choice

Icons and pictographs are still useful. Moreover, the number of studies that examined different forms of pictographs, icon arrays, or a comparison of the two suggests that this type of visualization alongside strong contextual information holds continued promise. One study [33] is particularly noteworthy with the finding that symbolic icons show the most promise for visualizing difficult to visualize health effects while iconic or indexical icons are more effective for specific body parts or symptoms.

III. Bar graphs, of varying types, remain a good choice

Bar graphs had been previously examined. More work in the last five years honed in on the characteristics of bar graphs. The findings remain the same, however, that simple bar graphs showing relationships between variables are best. Labels are key in situating the information the graph is representing. The results are still split somewhat on what type and construction of bar graph but since they are recognizable, there is potential to leverage this with more contextualized studies to determine the true effectiveness and comprehension of bar graphs.

IV. Interactive and personalized displays hold promise

Melonçon and Warner [6] pointed to future research on interactive displays and the two studies that directly looked at them, as well as several others that used features of interaction, suggest some of the promise of this visualization technique is coming to fruition. Interactive displays [46] urge caution because of the complexity of information and feasibility of using these in practice. Research [28] found interactive displays for personalized decision making highlighted that verbal descriptions must accompany numerical estimates.

V. Studies are beginning to focus on user's comprehension

Melonçon and Warner [6] noted that future research needed to focus on both attention and comprehension [47]. Numerous studies in this review attempted to assess comprehension of the information. The initial findings of several of the studies (e.g., [45], [37], [35]) indicate that comprehension and use preference may not align, which suggests an area of research for TPC scholars to pursue since they are experts at contexts. However, there is some concern over whether disciplines outside of TPC are using comprehension as a means to understand use of information or limiting their understanding of comprehension to surface level things such as readability and initial understanding. This is a key differentiator on whether information can be used to affect or change behaviors. Also, this study [7] found "our review shows that people's opinions and preferences do not typically translate into actual improvements in risk understanding" (605), which is something few studies have examined. Another study [48] specifically tested comprehension, and while the study design did so in a way that it was excluded from our empirical dataset, it shows promise for approaches for graphical displays in patient decision making.

OPPORTUNITIES FOR TPC

The future research calls and opportunities for TPC from previous research [6] still hold true and remain in large part unmaterialized. That is, TPC has many research opportunities in the realm of data visualizations. Most notably, the need for contextualized information aligns with one of the opportunities from 2017 [49] that argued context is a key facet for comprehension by users and the "single best thing" to improve communication practices. Research [50] found that clinicians within the hospital setting appreciated the visualizations but wanted the information to be further contextualized. In other words, one of the most important findings was not a preference of different visualization strategies but rather the importance of contextualizing the visualizations to make them more useful in a clinical setting. A study [18] came to a similar conclusion when they wrote that "nuances matter" in providing information to those who just found out they had

cancer. Those nuances included things such as the way information was presented and discussed in terms that were familiar to the patient rather than clinical use (e.g., conservative treatment was mis-understood) and to modify the accompanying written information to account for the patient's emotional state. Aligning with issues of context are those studies that are using data visualizations as part of a personalized communication plan around risk, adherence or compliance, and general information delivery.

While previous research [6] did not report on the issue of risk, there were several studies that framed their initial inquiries around visually displaying risk (e.g., [18], [21], [22], [16], [34]). However, these studies follow a science approach to research study design. What we mean by that is the insistence on rigid types of random control trials with different interventions alongside visual types ends up with conclusions that often cannot be replicated and more so, the conclusions are often not generalizable beyond the specific population that participated. A recent study in TPC [51] illustrates this point since it studies aspects of realism in risk communication. In other words, messy, often qualitative, research done in TPC would likely achieve better contextual results for specific populations while also providing better effective practices for construction of data visualizations.

A number of studies focused on numeracy ([44], [28], [38], [45]). One study [18] suggested that visualizations are especially important for those users with low numeracy or visual literacy. Further, a study [44] found that heart failure patients had difficulty in understanding numerical concepts in relation to their ongoing self-care and maintenance. Results are not in isolation but provide strong empirical evidence that much more attention needs to be paid to issues of health literacy and numeracy. TPC's research in literacy [52] needs to be expanded specific to issues of health literacy, which furthers previous calls [6].

We repeat Melonçon and Warner's [6] call for TPC scholars to take on lead roles in empirically based studies. The number of review essays all point to the need for more research and more systematic research that can be applied across medical domains. TPC scholars, more so than scholars in other disciplines, are uniquely positioned to focus on context, with an eye toward generalizable approaches that are much needed in research communicating complex health information through data visualizations.

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