The Science of Seeing Science: Examining the Visuality Hypothesis

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Abstract. Fundamental disciplinary differences may be traceable to the use of visual representations, with researchers in the physical and life sciences relying more heavily on visuality. Our goal was to examine how inscriptions are used by scientists in different disciplines. We analyzed 2,467 articles from journals in biology, criminology and criminal justice, gerontology, library and information science, medicine, psychology, and sociology. Proportion of page space dedicated to graphs, tables, and non-graph illustrations was calculated. A Visuality Index was defined as the proportion of page space dedicated to visual depictions of data and non-data information. An ANOVA indicated a statistically significant difference between disciplines, interaction between inscription type and discipline, with articles published in biology journals dedicating more page space to graphs. The significant overlap in inscription use and visuality indicates imperfect disciplinary demarcation, suggesting similar methodological and data analytic practices within a discipline and between subdisciplines.

Keywords: Disciplinary differences · Graphs and tables · Data analysis · Non-inferential analyses

1 Graph Use in Science

Whatever relates to extent and quantity may be represented by geometrical figures. Statistical projections which speak to the senses without fatiguing the mind, possess the advantage of fixing the attention on a great number of important facts.

Alexander D Humboldt, 1811 [1].

Graphical representations allow researchers to summarise data using numerical information in a form that is easily understood by researchers across disciplines [2–6]. The centrality of graphs to scientific inquiry implies that they are at the heart of scientific communication and the construction of scientific facts [7] and have a larger impact on the public than do written descriptions and mathematical proofs [8]. Visual images play an integral role in the comprehension of scientific theories and their constituent data.

Kevles [9] asserted that images allow scientifically dense results to be rendered accessible to non-scientists because, “the viewer transforms the static image into an active intellectual experience” [10, p. 9]. Illustrations afford description, classification, order, analysis, and comprehension [10] and modern scientific depictions often mirror early visualization strategies [9].

Latour’s [2] classic essay about the importance and usefulness of graphs laid out several fundamental graphical attributes, noting that they enable the transformation of transitory data into a stable, enduring depiction, and facilitate the detection of relationships between variables. Practical benefits of graphs include their easy transportability and reproducible nature, and their ability to be scaled depending upon the magnitude of the data that they represent. Furthermore, they greatly enhance scientific discussion and production of knowledge. Latour claimed that graphs were often central to a lucid and coherent argument, as, without them, scientists “stuttered, hesitated and talked nonsense and displayed every kind of political or cultural bias” (p. 22).

1.1 Disciplinary Differences in Graph and Table Use

Cleveland [4] analyzed graph use in 57 natural, mathematical, and social science journals that represented the hard-soft science continuum. Cleveland’s underlying hypothesis was that researchers include visual inscriptions only if they are considered central to the message conveyed in the paper. He calculated the proportion of total page area in an article dedicated to graphical displays (FGA) and found that natural scientists included more graphs in their publications than mathematical and social scientists. Although Cleveland’s results support the contention that “harder” sciences make use of more graphs than “softer” ones, he noted that differences in graph use could not be attributed to amount of data but to differences in data representation.

Smith and his colleagues [11] asked psychology faculty and graduate students to rate the scientific hardness of each of Cleveland’s [4] disciplines using a 10-point Likert scale. This subjective measure of hardness strongly correlated ($r = 0.97$) with Cleveland’s FGA ratings, with physics rated as the hardest and sociology rated as the softest. Thus, harder, more codified disciplines (i.e., natural sciences) used more graphs than softer, less codified disciplines (i.e., social sciences). Arsenault et al. [3] analyzed articles sampled from the same journals as Cleveland and argued that the relationship between FGA and disciplinary hardness could be generalized to other forms of visual displays, supporting the ‘visuality hypothesis’. Taken together, Smith and his colleagues [3; 6; 11, 12] have shown that graph use differs according to perceived scientific hardness both between and within a discipline; that is, researchers in harder areas use more graphs than those in softer areas. From a Latourian [2] point of view, these findings illustrate that graph use is proportional to the codification of disciplines, supporting the idea that graphs are a powerful communication device but that they are used differentially by researchers in different disciplines.

1.2 Purpose of the Current Study

This project is the result of 20 years of research, which began with the work of Larry Smith and Alan Stubbs examining inscription use in psychology (PSYC). The research

has expanded to include journals from biology (BIO), criminology and criminal justice (CCJ), gerontology (GERO), library and information sciences (LIS), medicine (MED), and sociology (SOC).¹ Our purpose was to examine the use of inscriptions in high impact natural and social science journals. Following Arsenault et al. [3], we were interested in examining disciplinary differences in the use of visual inscriptions (i.e., graphs + non-graph illustrations) and data presentation (i.e., graphs + tables). Further, we examined whether articles published in high impact journals include a wider variety of scientific inscriptions.

2 Method

2.1 Selecting and Coding the Sample

Journal titles per discipline were selected for the current study based on impact (i.e., *h-index*)² and/or journal prestige rankings and were sampled at 5 year intervals from 1980 to 2015, inclusive. Using an on-line random number generator, four issues per year and four articles per issue per journal were identified and selected for inclusion. We analyzed a total of 2,467 articles published in BIO ($k = 11, n = 324$)³ [13]; CCJ ($k = 16, n = 397$) [5]; GERO ($k = 25, n = 360$) [14]; LIS ($k = 11, n = 524$) [15]; MED ($k = 10, n = 300$); PSYC ($k = 12, n = 339$) [6; 12]; and SOC ($k = 7, n = 223$) journals. For each article, bibliographic factors were recorded and the proportion of page spaced dedicated to graphs, tables, and non-graph illustrations was calculated.

A graph was defined as a figure with a scale that displayed quantitative information [4]. Specific graph types (i.e., bar, scatter, line, 3D) were coded. Numbers and types of graphs, plus total graph area, and fractional graph area (FGA) [see 4] were recorded for each article. A table was defined as information presented in a series of rows and columns distinct from the main body of text [see 6] and were classified as a data or non-data table. Non-data tables typically presented qualitative information (i.e., lists, models). Numbers and types of tables, plus total table area and fractional table area (FTA) were recorded for each article [see 6]. A non-graph illustration was defined as any visual inscription (i.e., photograph, schematic, methodological illustration) that did not meet the criteria of a graph or table [5, 6]. Numbers and types of illustrations as well as total non-graph illustration area and fractional non-graph illustration area (FIA) were recorded for each article [see 6].

3 Results

3.1 Inscription Use Per Discipline

Following Cleveland [4] and Smith et al. [6], differences per inscription type per discipline were examined by comparing mean FGA, FTA, and FIA values. Overall, more

¹ Data from BIO, CCJ, GERO, LIS, and PSYC were previously published or presented.

² Hirsch's [16] *h-index* is a measures of scientific impact, based on the number of times journal articles are cited. Data were downloaded in April 2021 and are available from L. Best.

³ k = number of journals per discipline; n = number of articles per journal.

page space was devoted to tables (8.99%) than to graphs (5.20%) or non-graph illustrations (2.13%). Collectively, 14.23% of page space was dedicated to the presentation of data (i.e., graphs + tables). Mean FGA ranged from 1.64% for CCJ journal articles to 10.36% for PSYC journal articles. With respect to table use, mean FTA ranged from 6.08% for BIO journal articles to 12.69% for LIS journal articles. Mean FIA ranged from 0.21% for articles in CCJ journals to 6.52% for those in BIO.

To test specific differences in mean FGA, FTA, and FIA across disciplines, a mixed model ANOVA was conducted. The interaction between inscription type and discipline was statistically significant, $F(12, 4894) = 13.02, p < .001$, and post hoc analyses indicated that articles published in BIO and PSYC dedicated significantly more page space to graphical displays than did those in CRIM, GERO, and SOC ($ps < .001$); articles in PSYC had higher graph use than those in LIS and MED ($ps < .001$). Articles published in LIS journals used more tables than those in journals from all other disciplines ($ps < .001$). GERO, MED, and SOC articles consistently included more tables than articles published in BIO and PSYC. Articles in BIO journals dedicated more page space to non-graph illustrations ($M = 6.52\%$ vs. $< 3\%$ for each of the other disciplines; $p < .001$).

3.2 Data Presentation and Visuality Indices

To examine differences between data presentation techniques and overall use of visual inscriptions, a Visuality Index ($VI = FGA + FIA$) and a Total Data Presentation Index ($DPI = FGA + FTA$) were calculated [see 3].

Fig. 1. Disciplinary differences in Data Presentation (FGA + FTA) and Visuality (FGA + FIA).

As indicated in Fig. 1, there was more variability in VI than in DPI. The mean score (SD) on the DPI was 14.23% (0.22) with scores ranging from 8.18% for CCJ articles to 17.35% for LIS articles. A one-way ANOVA indicated disciplinary differences in DPI, $F(6, 2452) = 11.78, p < .001$, with CCJ articles having the lowest DPI. Articles published in BIO, LIS, and PSYC had consistently higher DPI than those published in CCJ, GERO, and SOC. The mean (SD) score on VI was 7.34% (0.21) with scores ranging

from 1.86% for CCJ articles to 15.06% for articles in BIO journals, with statistically significant disciplinary differences, $F(6, 2457) = 17.38, p < .001$. Articles published in BIO had a higher VI than other disciplines ($ps < .001$), with LIS, MED, and PSYC having a greater VI than CCJ, GERO, and SOC ($ps < .001$). To examine differences in VI and DPI for each discipline, a series of paired samples t-tests were conducted. With the exception of BIO, there were statistically significant differences between VI and DPI, indicating that researchers dedicate more space to data presentation than to visualization.

A Heterogeneity Index (HI), defined as the number of inscription types used in different articles, was calculated [see 3]. The HI ranged from 0 to 3, with HI = 0 indicating that an article included no graphs, tables, or illustrations and HI = 3 indicating the inclusion of at least one of each type of inscription. Overall, mean HI ranged from 0.92 (SD = 0.70) in CCJ articles to 2.14 (SD = 0.72) in BIO articles (see Fig. 2). As expected, there were statistically significant disciplinary differences, $F(6, 2452) = 91.17, p < .001$. Overall, BIO had the highest HI and CCJ had the lowest ($ps < .001$), with MED, PSYC, and SOC using, on average, approximately 1.6 different types of inscriptions per article. Finally, an examination of the relationship between average HI and *h*-index revealed a statistically significant correlation, $r(90) = 0.34, p < .001$. Interestingly, HI was more strongly correlated with *h*-index than mean DPI, $r(90) = 0.27, p = .032$, or VI, $r(90) = 0.26, p = .04$, suggesting that journal impact factor is associated with using a variety of scientific inscriptions.

Fig. 2. Percent of articles that used 0, 1, 2, or 3 different types of inscriptions.

4 Discussion

The current results summarise how scientists in different disciplines use scientific inscriptions and are generally consistent with previous research. This sample of articles included a variety of different types of inscriptions and, across all disciplines, almost 15% of article page space was dedicated to data presentation. As expected, there were statistically significant differences in graph use, with articles published in BIO, MED, and PSYC dedicating proportionally more page space to graphical displays [4; 6; 17]. It is important to note that, although, on average, articles published in the harder areas of science (BIO, MED) had higher FGAs than those published in the softer areas (CCJ, SOC), there was considerable disciplinary overlap.

Overall, tables were the most common scientific inscription, with approximately 14% of page space dedicated to tabular data presentations. With the exception of BIO, most researchers in most disciplines included fewer non-graph illustrations in their articles. Although there were statistically significant differences, the page space dedicated to data presentation ranged from approximately 8% in CCJ journals to 19% in LIS journals. This variability is likely attributable to how a graphical representation was defined (i.e., a display that contains quantitative information on a scale). For example, many articles in LIS included architectural plans, which served to increase the FGA in this discipline's journals. In light of disciplinary differences, we suggest that our data supports the assertion that all scientific disciplines have a large amount of data but that researchers convey their results using different types of inscriptions [4].

In both basic and applied settings, the primary responsibility of scientists is to ensure the meaningful contribution of research results. Visual inscriptions enhance communication between researchers [2] and allow the transfer of results to applied settings [18]. The incorporation of visualizations into the knowledge generation process allows stakeholders to fully appreciate the implications of specific research findings. Given the rise in data display techniques and the current focus on the creation of easily understandable visual representations of data, these results are useful. The current results suggest that the incorporation of a variety of inscriptions (see Fig. 2) is associated with the *h*-Index [16] of a journal and, thus, its overall impact factor. We would encourage researchers in all disciplines to think carefully about the message they want to convey and to create visual inscriptions that allow both experienced researchers and laypersons to appreciate research results. As Latour [2] noted, graphs allow people from different backgrounds to appreciate the significance of various scientific discoveries.

The empirical record is clear that graphical displays enhance our ability to discern data patterns and the current results illustrate that, across disciplines, most researchers incorporate inscriptions. They also support the link between visuality and scientific impact, in that articles published in BIO and PSYC journals had higher VI, with over 70% of articles containing at least one graph. Further, more than 60% of BIO articles contained at least one non-graph illustration, which demonstrates the importance placed on visuality. These disciplinary differences in inscription use speak to specific differences in theory development and codification [11]. Appropriately constructed illustrations augment the persuasiveness of research findings and, over the long term, help increase a discipline's codification. Through such efforts, the goals of knowledge cumulation and

transfer – translating empirical results into practical applications – will be met and yield benefits for both applied and research contexts.

4.1 Implications of Current Study

The current study adds to the body of literature concerning good data representation, analysis, and communication. To highlight the importance of graphs as a powerful supplement to inferential statistics, Wilkinson and the Task Force on Statistical Inference [19] advocated graphing one's data prior to statistical analyses. As these authors claimed, "graphics broadcast; statistics narrowcast" and plotting one's data prior to analysis may also help uncover coding errors, or threats to the integrity of the data [20, 21]. In science, measurement is central to discovery, and integrating graphical analyses and displays allows researchers to better understand the phenomena that they are studying.

4.2 Conclusions

The current results highlight several disciplinary differences in inscription use, with articles published in BIO and PSYC dedicating more page space to graphical presentation of data. Although some researchers in the social sciences include a variety of visual inscriptions in their publications, many researchers focus almost solely on tabular data presentation. Given the explosion of social media and news sites, we suggest that researchers should focus on overall communication strategies that extend beyond publication in academic journals and could include infographics designed for social media sites and well-designed videos that clearly communicate important information. The spread of misinformation is best countered by the spread of accurate information. Visual displays of data and, in fact, scientific methodologies, can slow the spread of false information. As Helen Purchase [22] noted, there are many different types of diagrams and, when designed properly, all serve to aid in the communication of science.

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