Constructing Knowledge

The Role of Graphs and Tables in Hard and Soft Psychology

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Because graphs provide a compact, rhetorically powerful way of representing research findings, recent theories of science have postulated their use as a distinguishing feature of science. Studies have shown that the use of graphs in journal articles correlates highly with the hardness of scientific fields, both across disciplines and across subfields of psychology. In contrast, the use of tables and inferential statistics in psychology is inversely related to subfield hardness, suggesting that the relationship between hardness and graph use is not attributable to differences in the use of quantitative data in subfields or their commitment to empiricism. Enhanced "graphicacy" among psychologists could contribute to the progress of psychological science by providing alternatives to significance testing and by facilitating communication across subfields.

"Facts" are visually supported beliefs shared by the community and visual demonstrations introduced in a persuasive process.
—Donald T. Campbell (1986, p. 121)

Visual displays are distinctively involved in scientific communication and in the very "construction" of scientific facts.
—Michael Lynch (1990, p. 153)

Among the long-standing issues addressed by philosophers of science are two questions of central importance and deceptive simplicity: What distinguishes science from nonscience and how do the various branches of science differ from one another? Given the prominent role played by science in the belief systems of the developed world, one might expect these questions to have clear answers. However, decades of efforts to resolve them have underscored how refractory they can be. For example, attempts to demarcate science from nonscience by means of such abstract methodological principles as falsifiability (Popper, 1963) have foundered on difficulties arising from the underdetermination of theories (Harding, 1976; Stam, 1992) and the fact that scientists commonly embrace theories without trying to test them (Kuhn, 1970). Similarly, attempts to delineate the distinguishing features of the various sciences by demarcating the hard sciences from the soft or by arraying them in a hierarchy have met with only limited success. For example, sociologists of science have sought to document measurable differences between the sciences in terms of levels of theoretical codification (Zuckerman & Merton, 1972), maturity or paradigm development (Lodahl & Gordon, 1972), consensus (Cole, 1983, 1992), and rates of change in research literatures (Price, 1970). The results of these efforts are typified by the conclusion drawn by Cole (1983) from his review of the literature on consensus and rates of progress across the hierarchy of sciences: "There are no systematic differences between sciences at the top and at the bottom of the hierarchy in either cognitive consensus or the rate at which new ideas are incorporated" (p. 111; see also Cole, 1992; Cozzens, 1985).

One consequence of these developments has been a growing reluctance of scholars who study science to draw distinctions between hard and soft science or even between science and nonscience. For example, Laudan (1977) depicted science as an organized problem-solving activity no different in principle from organized inquiry into metaphysics or theology (pp. 189–192), whereas others, notably Feyerabend (1978), have contended that science cannot be distinguished from nonscience on the basis of either its method or its results. According to Feyerabend, there is no scientific method—methodologically speaking, "anything goes" (Feyerabend, 1978, p. 39)—and usable results are produced by nonscientific as well as scientific endeavors. As one of many possible forms of social life, science is now often regarded as a diverse array of organized activities, sharing no common methodology and bearing many similarities to the practical activities of everyday life (Fuller, 1997; Galison & Stump, 1996; Pickering, 1992, 1995). A common claim is that all knowledge is rooted in local knowledge, the result of concrete situated practices and

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ongoing negotiations over the status of knowledge claims (Knorr-Cetina, 1981a; Rouse, 1987). As for the second question of how scientific disciplines differ from one another, science scholars are likewise resistant to drawing distinctions. Although some have recast the hard science–soft science distinction in terms of compact and diffuse disciplines (Toulmin, 1972), others find scant grounds for retaining such dichotomies. Thus Laudan (1977) denied the utility of any distinction between mature and immature sciences, arguing that no science ever achieves mature paradigmatic status in the Kuhnian sense, whereas Knorr-Cetina (1981b) denied that the natural and social sciences differ in method, both realms relying on interpretation to construct knowledge claims. Many observers have come to agree with Houser (1986) that the distinction of hard and soft science "has been revealed as a myth" (p. 367), and Cozzens (1985) has commented that traditional approaches to differentiating the sciences "have now largely been abandoned, for a variety of reasons" (p. 128). In the field of science studies (Biagioli, 1999), schemes for classifying disciplines on the basis of preconceived epistemological divides such as science–nonscience and hard science–soft science have been replaced by the *symmetry principle* (Bloor, 1991), according to which all forms of science must be studied without prejudice as to their epistemological merits or their degrees of "scientificity." For many scholars, in fact, "belief in the 'scientificity' of science has disappeared" (Latour, 1983, p. 142).

For psychologists, who have a long tradition of reflexive concern about the status of their field, such developments may be unsettling. For some, the decline of demarcations, with all their honorific and pejorative connotations, will be welcomed as liberating the field from the strictures of positivist scientism. For many others, however, the loss of such distinctions will be seen as depriving the field of any basis for staking a claim to scientific status. And perhaps most will harbor the lingering suspicion that adherence to the symmetry principle—with its prescription for agnosticism about scientific status—obscures more than it reveals about the nature of science or psychology's place among the sciences. As always, the stakes involved in drawing boundaries between science and nonscience are high (Gieryn, 1999), and the degrees of scientificity ascribed to scientific disciplines remain consequential, not least in terms of a discipline's credibility (perceived or real) in its cultural context.

For those not ready to abandon belief in the scientificity of science, it is perhaps significant that recent work in science studies provides new leads on the problem of classifying the sciences. Seeking ways to understand science that avoid the suspect philosophical presuppositions of the past, a number of investigators have turned to fine-grained field studies of everyday scientific activity. Prepared in the form of laboratory ethnographies, these investigations analyze in detail the practices by which scientists construct, negotiate, and communicate scientific findings. Critical to these practices are the material cultures of scientific work sites, including the instrumentation used, shared techniques for transforming and analyzing data, and the technologies of representation used in formulating and debating research findings (Golinski, 1998; Woolgar, 1988). Especially important for the construction and negotiation of knowledge claims are the representational techniques that Latour and Woolgar (1986) called "inscription devices" (p. 51)—such as graphs, tables, and diagrams—which scientists use in recruiting allies to their viewpoint and persuading members of competing camps. As understood by rhetoricians and historians of science, it is through such persuasive processes that inscriptions achieve their effect of building consensus and allowing the tentative knowledge claims generated at local research sites to become stabilized and transformed into widely accepted facts.

In this article, we show how the focus on inscription practices arising from fine-grained field studies of science can be brought to bear on the venerable problem of differentiating the sciences. Neither denying differences nor enshrining them in abstract concepts of method, we argue that differences between the branches of science are related to the uneven distribution of concrete practices of representation, conceived as crucial rhetorical resources for constructing and defending knowledge claims. We begin by considering the centrality of inscriptions to science and presenting Bruno Latour's theory of graphism, arguing that graphs represent an especially powerful means of knowledge construction because of specific features lacked by tables and other inscription devices. We then review evidence from previous studies that graphs are used differentially across the hard and soft fields of science at large and of psychology in particular. For the case of psychology, we then show that the graphism–hardness relationship cannot readily be attributed to subfield differences in the use of quantitative data, because the use of numerical tables and

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inferential statistics is inversely related to subfield hardness. Finally, we consider the implications of the graphism thesis for the vexing question of whether psychology can or even should attempt to emulate other sciences.

The Ubiquity of Inscriptions

One way to appreciate the role of inscriptions in science is to consider the part they play in the hallowed process of observation. Although empiricists have long presumed that science begins, epistemologically speaking, with the observation of entities in a domain, the remarkable fact is that scientists rarely observe their subject matter at all (Hacking, 1983, chap. 10; Latour, 1990; Lynch & Woolgar, 1990). Nuclear physicists look at photographs of bubble chambers (not subatomic particles), chemists observe micrographs and spectrographs (not chemical samples), biologists examine chromatographs and instrument printouts (not organisms), and economists observe charts of productivity and spending (not factory workers or mall shoppers). Similar cases abound in psychology. For example, operant conditioners look at graphs and counters (not pigeons or rats, which remain concealed from view in conditioning chambers), and personality theorists scrutinize Minnesota Multiphasic Personality Inventory profiles and factor analysis charts (not traits or even the participants filling out personality inventories). Even clinical researchers devote much of their time to reviewing data from assessment instruments, coding client journals, and monitoring heart rate recordings (not observing actual problem behaviors). To the extent that objects in a given domain of science are handled and observed at all, such tasks are typically left to laboratory technicians and graduate assistants. What scientists see instead are inscriptions—and, for them, it is inscriptions that constitute the face of nature (Golinski, 1998; Lynch, 1990; Lynch & Woolgar, 1990; Woolgar, 1988). As Latour (1990) put it, most phenomena of nature "are never seen but through the 'clothed' eye of inscription devices" (p. 42), and "scientists start seeing something once they stop looking at nature and look exclusively and obsessively at . . . inscriptions" (p. 39). In sum, the facts that emerge from scientific research exist as inscriptions—the relatively durable material artifacts of science—not as the sensory impressions of traditional empiricism, which are, in any case, too fleeting and variable to support the epistemological role traditionally ascribed to them.

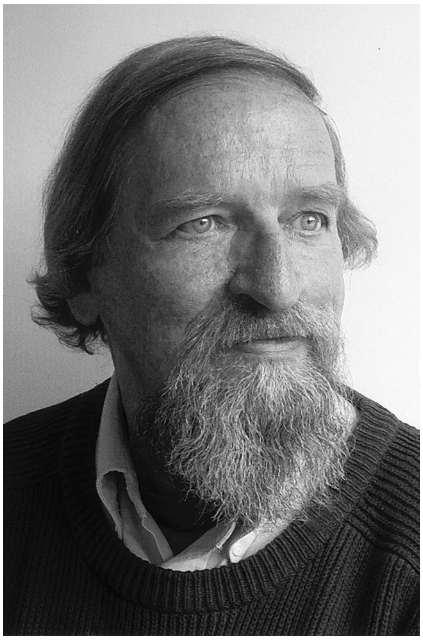
Although inscriptions thus have a certain epistemological priority in the early stage of observation, their role in science by no means ends there. They also play a crucial role in the detection of novel empirical relationships, the assessment of data quality, the stabilization of facts, the formation of hypotheses, the testing of theories, and the communication of knowledge to other scientists and their public audiences. Inscriptions mediate thought and communication at every site of knowledge production and consumption, from informal sketchings at the laboratory bench to presentations at scientific meetings, from journal articles to the dissemination of findings in textbooks and popular media. Inscriptions are what scientists work with, infusing every phase of scientific activity (Lynch, 1990). Small wonder that they have been called "the treasures of science" (De Mey, 1992, p. xii) or that science scholars speak of their power to constitute phenomena and to provide "ocular proof" (Golinski, 1998, p. 145).

The Power of Graphs

Latour's Graphism Thesis

However, to speak of inscriptions as the ubiquitous treasures of science does not mean that all inscriptions are equally valuable. One conclusion that has emerged from ethnographies of science is that graphs represent an especially potent and persuasive type of visual device (Amann & Knorr-Cetina, 1990; Latour & Woolgar, 1986; Lynch, 1990), a conclusion shared by a growing number of historians of science (Hankins, 1999), rhetoricians of science (Gross, 1990), and scholars who analyze scientific data displays (Tufte, 1983).

In his classic essay "Drawing Things Together," Latour (1990) laid out the features of graphs that make them so powerful. First, they are *readable*, capable of rendering complex data sets into easily apprehended images that exploit the human capacity for perceiving visual patterns. In this way, they make possible the "virtual witnessing" (Shapin & Schaffer, 1985, p. 60) of research outcomes by scientists far removed from the original sites of data collection. Second, graphs are *scalable*, meaning that through simple alterations of scale, they can make visible a variety of phenomena—ranging from quarks and ion pumps to gross national products—that are ordinarily invisible because of their size, duration, or abstractness. By allowing scales of time and place to be transcended in ways that otherwise defy comprehension, they function as "revelatory objects" (Lynch, 1990, p. 154). Third, as easily ma-



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nipulated artifacts, graphs are *combinable*, allowing them to be collated and superimposed in various ways. Such combinations can reveal novel connections between seemingly unrelated phenomena and encourage abstraction from details to generalities by facilitating comparisons between different data sets or between data and theoretical curves. The manipulation of graphs into varied combinations thus allows scientists to see phenomena synoptically by "drawing things together," a feature that contributes to theoretical integration. Fourth, graphs are *immutable*. They serve to stabilize ephemeral observations by converting them into relatively permanent traces that express invariant patterns in phenomena; as such, they are immutable both in the sense of preserving invariances across transformations (i.e., when redrawn or reconfigured) and in the sense of becoming enduring objects of contention among scientists. Fifth, graphs are *mobile*, meaning that (unlike the objects of research themselves) they can be transported from one laboratory to another, from laboratories to conferences, or from research sites to sites of application. Such mobility is crucial for establishing consensual ways of seeing phenomena and for the diffusion of novel facts through research networks that stabilize them as accepted knowledge. Sixth and crucially, as immutable mobiles, graphs are *persuasive*. They serve to convince other scientists of the validity of one's evidence, thereby aiding in the recruitment of allies to one's viewpoint—hence Latour's (1990) motto that "inscriptions allow *conscription*" (p. 50, italics in original). According to Latour, graphs reduce resistance to tentative knowledge claims by raising the cost of dissent, forcing doubters to marshal their own evidence in even better graphs. In such cases, competition over knowledge claims is carried out through a "cascade of inscriptions" (Latour, 1990, p. 42), ending only when one last visual display proves powerful enough to tip the balance of power. "He who visualizes badly," wrote Latour (1990), "loses the encounter; his fact does not hold" (p. 41).

In light of the virtues of graphs as rhetorically potent immutable mobiles, it is not surprising that modern research centers have been characterized as organized sites for persuasion by means of visual inscriptions (Latour & Woolgar, 1986). When science is closely observed—as actually practiced at research sites—its vaunted intersubjectivity is seen to depend on the ability of successful scientists to mobilize consensus on knowledge claims, and, for Latour (1990), such consensus emerges through debate and negotiation over graphical inscriptions. Tentative claims become hard facts to the extent that they are made resistant to deconstruction by being codified into "visual displays for consensual 'seeing' and 'knowing' " (Lynch, 1990, p. 155).

What ethnographers of science find at research sites is not workers who are more rational or objective or better falsifiers than nonscientists but rather practical reasoners who are better equipped with repertoires of powerful inscription devices. Scientists in action surround themselves with graphical displays that make productive talk possible (Roth & McGinn, 1997). When deprived of those resources, scientists lose their shared rhetorical space and are found to stutter, hesitate, and talk nonsense (Latour, 1990, p. 22), regaining their powers of articulation only when new inscriptions are scribbled with whatever materials are at hand. In view of the striking dependence of scientists on such inscriptions, Latour (1990) concluded that scientists display an extraordinary "obsession for graphism" (p. 39) and that their prevalent use of graphs is, in fact, what distinguishes science from nonscience.

The claim that graphism is so pervasive and central to science as to constitute a distinguishing feature may appear hyperbolic, especially to those accustomed to the usual philosophical proposals for demarcating science from nonscience. The effects of science on modern life simply seem too vast to be attributed to such a mundane cause as everyday graphical practices, requiring instead abstract principles such as verifiability or falsifiability. But Latour (1990) argued that large effects—such as the powerful cultural role of science—can, in fact, arise from small-scale, local practices of knowledge production that are obsessively reiterated daily at research sites. Philosophers of science, misled by their search for grand principles to explain science's vast effects, have been blind to the everyday conduct of science revealed by the ethnographer's field studies, and the plausibility of their methodological principles evaporates once the ethnographer enters a laboratory and begins observing what actually takes place. When it comes to methodological principles, Feyerabend is only half right: "Anything goes, except the inscription devices" (Latour, 1983, p. 161). For Latour, graphical inscriptions—understood as widely used immutable mobiles with epistemological and rhetorical power—are indeed responsible for the preeminence of science.

Andrea Bastiani Archibald

Graphs Versus Tables

Tables and graphs are the two most commonly used types of inscription in science, at least in journal publications. Compared with graphs, tables have the advantage of showing precise numerical values (which can be difficult to read with accuracy off a graph), but they lack the capacity of graphs to reveal subtle patterns in data or to be superimposed in synoptic displays. A number of scholars who study inscription devices in science have argued that tables are a rhetorically primitive means of data representation, lacking the readability of graphs as well as their power to promote theoretical integration and mobilize consensus among competing camps of scientists. Bastide (1990) concluded from her study of the iconography of scientific texts that many scientists prefer to avoid tables because they are perceptually inefficient, rhetorically unconvincing, and often "perfectly undecipherable" (p. 214). In a study of representational practices among limnologists, Krohn (1991) found that tables were, at most, quickly scanned for salient features before being converted into graphs for detailed perusal and use in model building. Giere (1988) found that nuclear physicists rely on graphs, rather than on tables and statistical inference, to assess the fit of data to theory (but see Galison, 1997), and Bazerman (1988) reported that physicists working in the field of spectroscopy gradually shifted from the use of tables to the use of graphs as the field matured over the past century. The difficulty of discerning patterns in tabular data is captured in the 19th-century dictum that "getting information from a table is like extracting sunlight from a cucumber" (see Wainer & Thissen, 1981, p. 236). Indeed, some experimental research on human perception suggests that tables are inferior to graphs for conveying trends in data, differing by nearly an order of magnitude on a standard measure of information transfer (Legge, Gu, & Luebker, 1989; but see Meyer, Shinar, & Leiser, 1997). As Doherty, Tweney, and Mynatt (1981) observed, "we know from several lines of research that people are good at detecting weak signals in perceptual tasks, but not very good at making comparable judgments about numerical data" (p. 263). Nonetheless, the apparent preference of natural scientists for graphs over tables may not be shared by social scientists; as noted by J. A. Davis and Jacobs (1968), "statistical tables are the most common form of documentation used by the quantitative social scientists" (p. 497).

The Use of Inscriptions Across the Sciences

The work of Latour and others who study inscription devices in science has testable implications for the understanding of science, including some long-standing issues about the status of the special sciences. If graphical inscriptions are central to science—perhaps even a distinguishing feature—then it should be possible to interpret the status of scientific disciplines and subdisciplines in terms of their data-representation practices, specifically, their differential uses of more powerful (graphs) and less powerful (tables) inscription devices. The Latourian analysis of inscriptions implies that the harder sciences, long thought to work with relatively well-defined phenomena and well-stabilized facts, would be expected to exhibit relatively high rates of graph use. More generally, the use of graphs in various fields should be proportional to the scientificity of those fields. In addition, Latour's analysis implies that the use of graphs possessing specific features that encourage synopticality—the drawing of things together—would also be proportional to the hardness of fields. Finally, the foregoing considerations about tables imply that, in contrast with graphs, their use may be inversely related to the hardness of fields. In this section, we describe data bearing on these issues.

Graph Use Across Disciplines

In an extensive survey of the use of graphs in scientific journals, Cleveland (1984) studied random samples of articles drawn from a number of scientific fields. On the assumption that page space in journals is a valuable limited resource, he measured graph use in terms of *fractional graph area* (FGA), which represents the proportion of the total page area in an article that is devoted to graphs. Using this measure, he found that graph use varied widely across journals, with the mean FGA for chemistry journals being .18 as compared with a mean FGA for sociology journals of .01 (a nearly 20-fold difference); the other sciences fell between these extremes. Overall, FGA for the four hard sciences in the survey (chemistry, physics, biology, and medicine) was .14 as compared with .03 for the three soft sciences (sociology, economics, and psychology), leading Cleveland (1984) to conclude that "graph usage is much greater among the natural science journals than among the social science . . . journals" (p. 265). To gain a closer look at the relationship of graph use to disciplinary status,

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Smith, Best, Stubbs, Johnston, and Archibald (2000) reanalyzed Cleveland's outcomes in relation to the hardness of disciplines. As a measure of disciplinary hardness, Likert-scale ratings of hardness were collected from a group of psychologists. Their rankings closely matched rankings of scientific fields made previously by other groups of scientists (Lodahl & Gordon, 1972).[1]

When FGA was plotted against rated hardness for the seven disciplines, the relationship proved to be strong, $r = .97$, $p < .01$ (see Figure 1A). This finding of proportionality between graph use and the hardness of fields supports the Latourian thesis that graphism is a hallmark of science and that the scientificity of disciplines is related to their use of rhetorically effective visual inscriptions. Moreover, the strength of the observed relationship is unusual in the literature on disciplinary differences. To underscore this point, Smith et al. (2000) correlated their hardness ratings with 21 other variables previously proposed by sociologists of science as differentiating between scientific disciplines. They found that fully one third of the proposed correlates failed even to correlate with hardness in the predicted direction and that only two—journal rejection rate (Hargens, 1988) and citation concentration by author (Cole, 1992)—exhibited correlations that reached statistical significance. Of these, only the citation concentration measure correlated with rated hardness as strongly as did FGA.

Graph Use in Hard and Soft Psychology

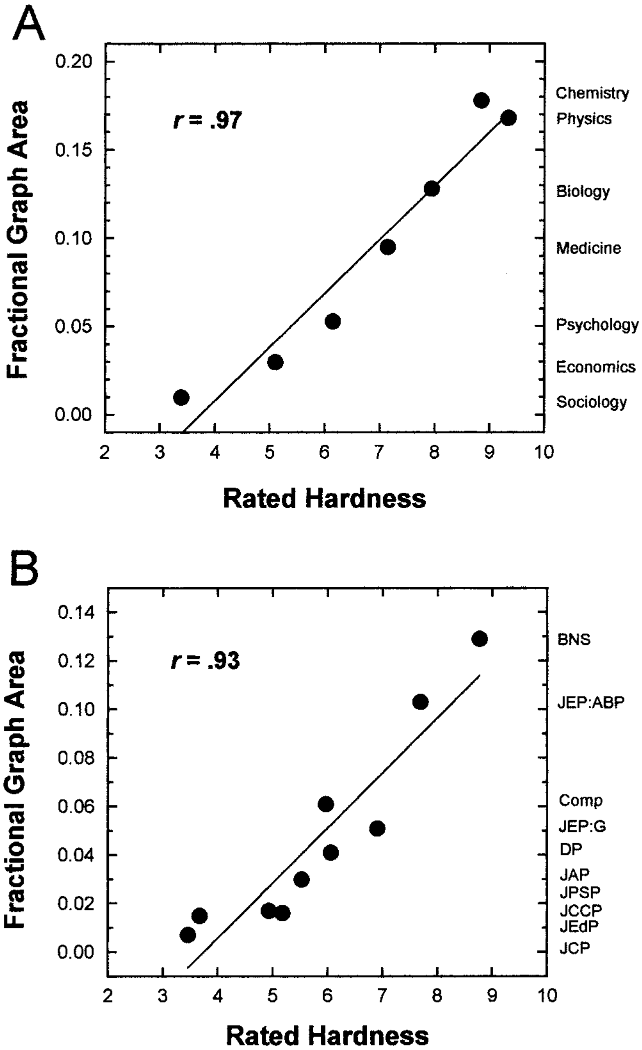
Given these findings, it is of interest to ask whether the relation of graph use to the hardness of fields is reflected in the subfields of psychology. Scientific disciplines typically encompass a wide range of subfields that can differ in methods and outlook and hence are often regarded as representing various degrees of hardness and softness. Such hierarchies of scientificity have been noted in physics (where particle physics is regarded as more mature and better codified than, say, solid state physics; Hagstrom, 1965) and in biology (where molecular biology is regarded as being harder than ecology or taxonomy; C. C. Davis, 1963). Of course, such differences are not unknown in psychology. To see whether graphical inscription practices are differentially distributed across the spectrum of psychology's subfields, Smith et al. (2000) obtained ratings of 25 American Psychological Association (APA) journals in terms of the hardness or softness of the subfields they represent (the respondents were the same as for the disciplinary ratings, as was the 10-point Likert scale). The journals were then ranked according to rated hardness, and two were selected from each quintile of ratings. From each of the resulting 10 journals, 16 articles were randomly drawn from the years 1980–1995 and were scored for their graph use following Cleveland's (1984) procedure. As with the scientific disciplines, the subfields of psychology varied widely in their use of graphs, with mean FGAs ranging from a high of .13 for *Behavioral Neuroscience* (comparable to the mean of .13 for biology) to a low of .01 for the *Journal of Counseling Psychology* (matching the mean of .01 for sociology). When the graph-use data were plotted against the journal hardness ratings, the relationship was again strong, $r = .93$, $p < .01$ (see Figure 1B). As before, this result lends credence to the Latourian notion that the use of graphs—with all their virtues as immutable mobiles—is closely related to the scientificity of fields.

As noted above, Latour's (1990) analysis of graphs emphasizes their ability to draw things together by facilitating comparisons between different findings or between data and theoretical expectations. This synoptic property of graphs has also been stressed by graphical theorists who advocate overlaying of data sets and arraying parallel graph segments in multiple panels to highlight the relevant similarities and differences in data (Cleveland, 1994; Tufte, 1983; Wainer & Thissen, 1981). In line with the view that multiple-panel arrays represent a rhetorically sophisticated form of graphism, Bazerman (1988) found that spectroscopists made increasing use of multipanel graphs as their field matured over a period of decades. In light of these considerations, we returned to the sample of articles previously studied by Smith et al. (2000) to determine whether

[1] The previous rankings, averaged across the four groups that made them (chemists, physicists, sociologists, and political scientists), correlated highly ($r_s = .94$) with Smith et al.'s (2000) ratings. The latter ratings were also validated against two other indices of disciplinary hardness (Ashar & Shapiro, 1990; Biglan, 1973), yielding correlations in the range of .91–.94. See Smith et al. for further details and Hargens and Kelly-Wilson (1994) for discussion of various measures of disciplinary status. The instructions for Smith et al.'s rating task began as follows:

> It is commonly believed in our culture that a distinction can be drawn between the "hard" sciences and the "soft" sciences. Although these categories are not always clear-cut, most people have some sense of what the hard–soft distinction means. In the survey you are being asked to fill out, we are interested in your impressions of which areas of science can be considered relatively hard and which can be considered relatively soft. (Smith et al., 2000, p. 77)

Figure 1
Proportion of Page Space Devoted to Graphs as a Function of the Rated Hardness of 7 Scientific Disciplines (A) and 10 Psychology Journals (B)



Note. The psychology journals (with their mean hardness ratings) were *Journal of Counseling Psychology* (JCP; 3.46), *Journal of Educational Psychology* (JEdP; 3.67), *Journal of Consulting and Clinical Psychology* (JCCP; 4.93), *Journal of Personality and Social Psychology* (JPSP; 5.18), *Journal of Abnormal Psychology* (JAP; 5.53), *Journal of Comparative Psychology* (Comp; 5.97), *Developmental Psychology* (DP; 6.06), *Journal of Experimental Psychology: General* (JEP:G; 6.91), *Journal of Experimental Psychology: Animal Behavior Processes* (JEP:ABP; 7.69), and *Behavioral Neuroscience* (BNS; 8.77). From "Scientific Graphs and the Hierarchy of the Sciences: A Latourian Survey of Inscription Practices," by L. D. Smith, L. A. Best, D. A. Stubbs, J. Johnston, and A. B. Archibald, 2000, *Social Studies of Science, 30,* p. 78 and p. 81. Copyright 2000 by Sage Publications. Adapted with permission.

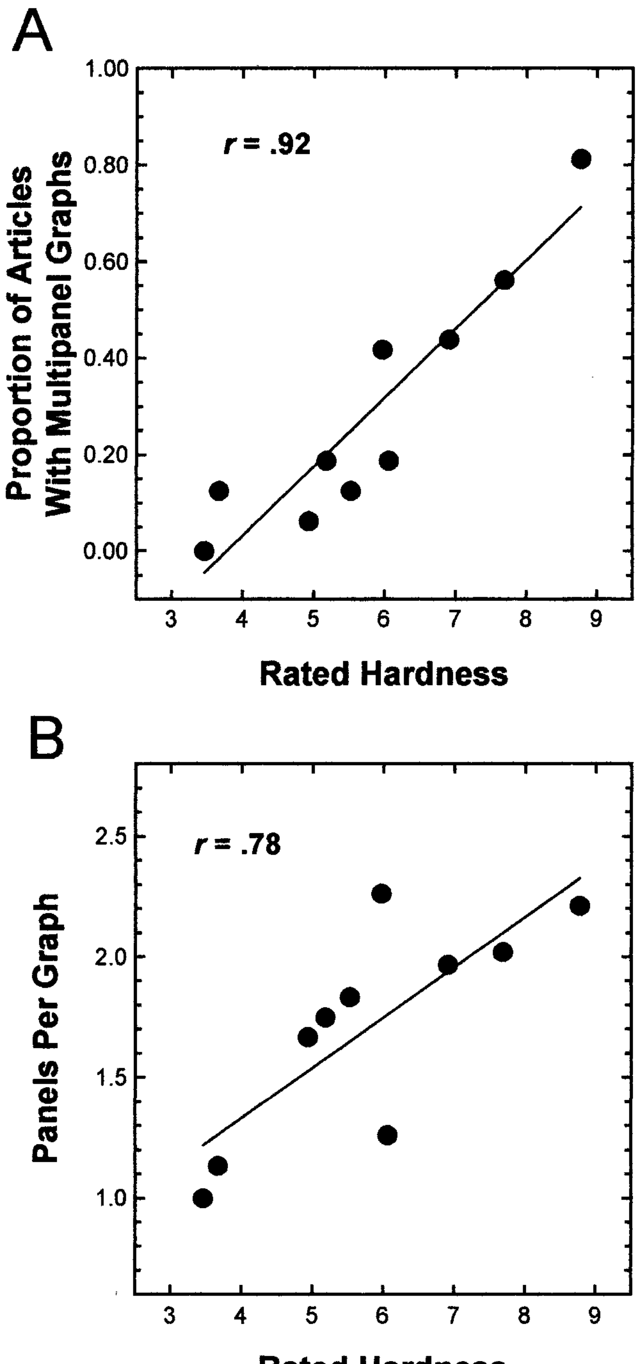
the use of multipanel graphs, like the use of graphs in general, is differentially distributed across the subfields of psychology as a function of their rated hardness. As with graphs in general, there was a wide range of multipanel graph use: Whereas none of the articles in the softest rated journal included such graphs, over 80% of the articles in the hardest rated journal did so. Figure 2A shows the overall relationship between hardness and the proportion of articles in each journal that contained at least one multipanel graph, $r = .92$, $p < .01$. To control for differences in the number of graphs among the journals, we prepared Figure 2B to show the mean number of panels per graph; the relationship, although weaker, is again significant, $r = .78$, $p < .01$. Thus, regardless of which measure is used to index multipanel graph use, the results support the conclusion that this type of synoptic visual practice is more common in psychology's harder subfields.

Table Use in Psychology

As discussed above, tables have been compared unfavorably with graphs in terms of their relative readability, ease of comprehension, combinability, and overall rhetorical effectiveness. To determine whether the use of tables is related to the hardness of psychological subfields, we returned again to the sample of articles studied by Smith et al. (2000), recording table use as *fractional table area* (FTA). The measure was computed exactly as for fractional graph area and included only tables that contained data (i.e., tables reporting such information as the order of experimental conditions were excluded from the analysis). The results of the survey showed that, as for the case of graphs, the journals differed widely in rates of table use, ranging from a high of .12 for the *Journal of Clinical and Consulting Psychology* to a low of .01 for *Behavioral Neuroscience*. Taken together, the five softest rated journals had a mean FTA of .10, compared with a mean of .05 for the five hardest rated journals. As expected on the basis of inscription theorists' analysis of tables, table use was inversely related to the hardness of subfields, $r = -.86$, $p < .01$ (see Figure 3A, filled symbols). This finding coheres with Latour's (1990) view that the harder, more theoretically codified fields of science tend to use rhetorically powerful inscriptions, whereas the softer, more empirical fields tend to use weaker types. In Latour's words, "to go from 'empirical' to 'theoretical' sciences is to go from slower to faster mobiles, from more mutable to less mutable inscriptions" (Latour, 1990, p. 47).

To facilitate comparison of the results for table and graph use, we include the data on graph use from Figure 1 in Figure 3A. As can be seen from the regression lines, table use declined across levels of rated hardness as graph use increased, resulting in large differences at the two ends of the spectrum. In the two softest rated journals, the ratio of graph use to table use was about 1:10, whereas the ratio for the hardest rated journal was reversed, approaching 10:1. Such differential use of the two data-display techniques may well occur also across the disciplines of science at large. Although Cleveland (1984) did not include a measure of table use in his survey of graph use among disciplines, he did report that "many of the social science journals have much data yet make very little use of graphs" (p. 265), the social science data presumably being shown in tabular format (as indicated by J. A. Davis & Jacobs, 1968). The regression lines in Figure 3 also reveal that table use in

Figure 2
Proportion of Articles Containing Multiple-Panel Graphs (A) and the Number of Panels Per Graph (B) as a Function of the Rated Hardness of 10 Psychology Journals



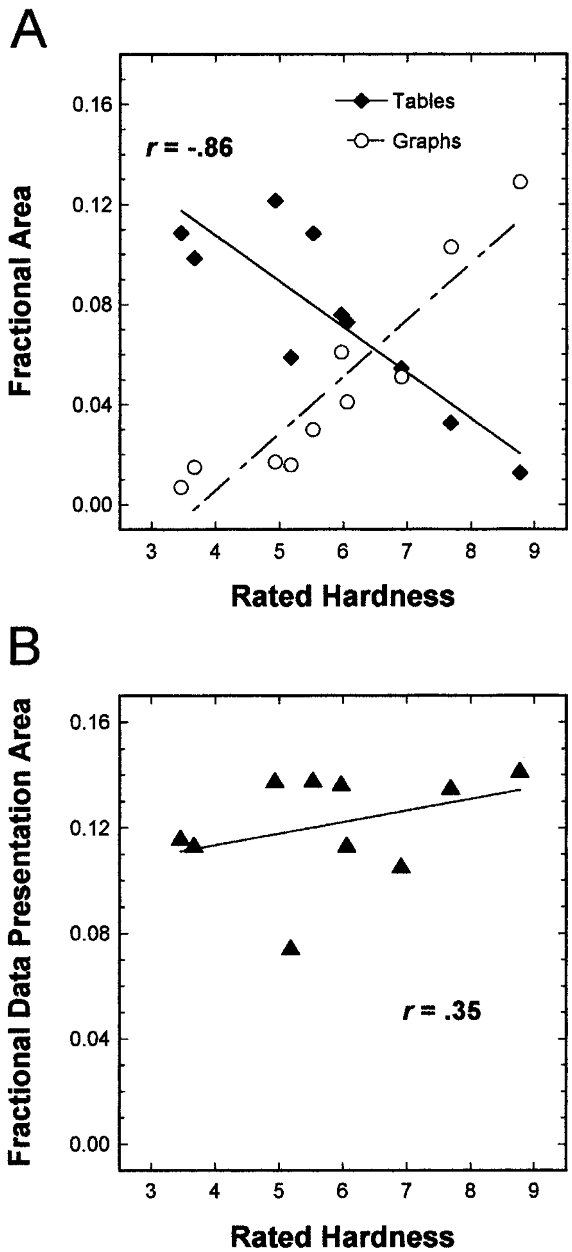
the psychology journals declined across hardness levels at about the same rate that graph use increased. As a result, the proportion of page space devoted to total data presentation (graphs plus tables) was fairly constant across the range of subfields, showing only a slight and nonsignificant correlation with hardness, $r = .35$, $p > .05$ (see Figure 3B). The relative flatness of the regression line for total data-presentation area suggests an interesting conclusion: In psychology, at least, fields varying in hardness do not differ in amount of page space allocated to data displays, but only in the means of representing those data. In other words, there is little evidence that softer subfields are less data oriented or less empirical than their harder counterparts.

Inscriptions and Quantification: The Relation of Graphs, Tables, and Statistics

The suggestion that subfields of psychology differ in their inscription practices, not in their degree of commitment to empiricism, coheres well with Latour's graphism thesis, pointing once again to the use of graphs as a distinctive aspect of science. But before drawing conclusions about the uniqueness of graphism as a correlate of scientificity, it is worth considering an important alternative possibility. One natural interpretation of the close link between graphism and scientificity is that both depend on a third factor, namely, the degree of quantification in scientific fields. This interpretation gains initial plausibility from the fact that many people first learn graphing skills in connection with the equations of analytic geometry, as well as from the work of historians of science (e.g., Koyré, 1968) who view the mathematization of scientific fields as an important component of their maturation into hard sciences (a view reflected in the occasional designation of sciences as *exact* or *inexact*). However, there is also ample reason to question whether the quantification of scientific fields is closely related to either their hardness or their use of graphs. For example, economics is among the most quantified of all scientific fields—its data come in numerical form and its journals are replete with equations and mathematical models—yet it consistently ranks low in both hardness and its use of graphs (see Figure 1). More generally, commentators have noted that the social sciences, despite ranking low in scientificity, generate large volumes of quantitative data, even to the point of becoming swamped in them (Porter, 1995), an observation consistent with Cleveland's (1984) report that social science journals have plentiful data but few graphs. Further dissociating graphism from mathematization is the fact that even in the harder sciences, graphs are often used in atheoretical contexts, including domains completely lacking in mathematical theory (Smith et al., 2000).

The question of whether graphism is a by-product of quantification rather than a unique correlate of scientificity is a difficult one, but it is an issue amenable to empirical test. In the sociology of science, three indices have been used to measure the quantitativeness of scientific fields: (a) the number of equations appearing in papers (Bazerman, 1988), (b) the use of numerical tables (McNamee & Willis, 1994; Storer, 1967), and (c) the use of statistical procedures (Lindsey, 1978). The use of equations was not a feasible measure for our sample of psychology articles, because

Figure 3
Proportions of Page Space Devoted to Data Displays



Note. A: Proportion of page space devoted to tabular presentation of data (filled symbols) as a function of the rated hardness of 10 psychology journals. Fractional graph area (open symbols) is shown for comparison purposes. B: Proportion of page space devoted to total data presentation (the sum of the table and graph areas) as a function of rated hardness.

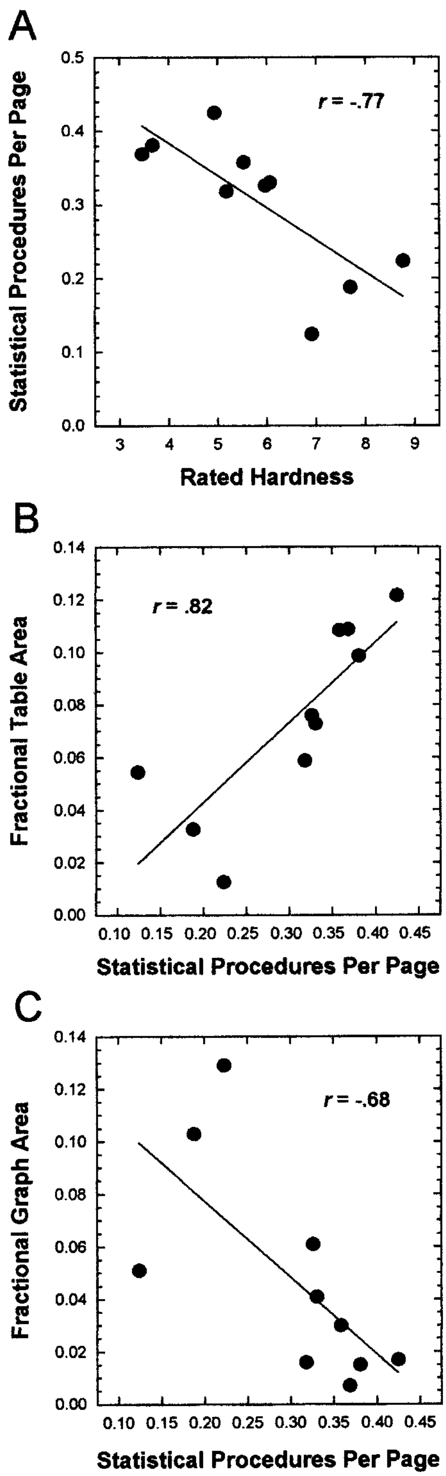
equations were virtually absent from them.[2] The use of tables, as reported in Figure 3, proved to be negatively correlated with both the hardness of subdisciplines and their graph use. To the extent that tables provide a valid index of quantitativeness, this finding clearly weighs against the view that the relationship between graphism and scientificity can be attributed to how quantified fields are. To address the issue with the third measure of quantitativeness—the use of statistical procedures—we returned once again to Smith et al.'s (2000) sample of articles and recorded the use of inferential statistics in them. The measure was the number of different statistical procedures used; thus, an article that used only chi-square tests would be scored as a 1, regardless of how many times the tests were performed, and an article that used chi-square tests, analyses of variance, and Scheffé tests would be scored as a 3. To control for differences in article length, we then divided the number of procedures used by the number of pages in the article.[3]

The results showed wide variations in statistical usage, ranging from a high of 0.42 procedures per page for the *Journal of Consulting and Clinical Psychology* to a low of 0.12 for the *Journal of Experimental Psychology: General*. The five softest rated journals used statistics at a mean rate of 0.37 procedures per page, compared with a mean of 0.24 procedures per page for the five hardest rated journals. When plotted against rated hardness (see Figure 4A), there was an inverse relationship between hardness and statistical usage, $r = -.77$, $p < .05$. This result accords with the long-standing view of Meehl (1978) that softer fields of science rely more on statistical inference than do harder fields, both across disciplines and within psychology. The result also suggests that hardness is not readily identifiable with quantification in any straightforward way; in fact, to the extent that the use of statistics represents a valid index of quantitativeness, the relationship is the reverse of what would be expected if graphism is a mere by-product of quantification. As for the relationship between inscription practices and statistical usage, Figures 4B and 4C show that table use is directly related to the use of statistical inference, $r = .82$, $p < .01$, whereas graph use is inversely related to it, $r = -.68$, $p < .05$. These correlations are again consistent with Latour's thesis that graphism is a unique correlate of scientificity. The inverse relation between the use of graphs and statistics also supports the thesis of Tweney (in press) that graphs constitute a distinct means of inference in their own right and thus represent an

[2] Perhaps surprisingly, there appears to be little association between the use of equations and the use of graphs in science at large. In a partial replication and extension of Cleveland's (1984) study, Arsenault, Beauchamp, and Smith (2001) randomly sampled 180 articles from the same journals used by Cleveland and recorded the number of equations in each article along with FGA. Graph use again correlated highly with rated hardness ($r = .93$, $p < .01$), but the use of equations was not closely related to either hardness ($r = .10$, $p > .05$) or FGA ($r = .18$, $p > .05$).

[3] Because nearly all (95%) of the articles in our sample used inferential statistics, we could not use the presence or absence of statistics as a binary variable, as Lindsey (1978) did. We also attempted to record the number of instances of statistical hypothesis tests in each article (i.e., tokens not types) but found it impossible to count separate instances of the tests (largely because of statements such as "no other interactions were significant" in cases where the number of interactions tested for was not specified). In recording the number of procedures used, our intent was to measure general reliance on inferential statistics.

Figure 4
Use of Statistical Procedures, Tables, and Graphs in Journals



Note. A: The number of statistical procedures per page used in 10 psychology journals. B: The relationship between fractional table area and the number of statistical procedures per page used by the journals. C: The relationship between fractional graph area and the number of statistical procedures per page.

alternative to statistical inference, not a mere complement to numerical methods (Best, Smith, & Stubbs, 2001; Loftus, 1993; on the concept of visual inference, see Fisch, 2001; Wampold & Furlong, 1981).[4]

Among those who have commented on the abundance of quantitative data in the social sciences is the philosopher of science Ian Hacking (1983), whose reflections on the status of the social sciences are telling: "Social scientists don't lack experiment; they don't lack calculation; they don't lack speculation; they lack the collaboration of the three" (p. 249). If Latour (1990) is right that graphs—by virtue of their ability to draw things together—are uniquely suited for the coordination of scientific activities (experimental, numerical, and theoretical), then graphical practices may hold promise for bringing about the kind of collaboration that Hacking finds lacking in the social sciences.

Graphism for All?

On both theoretical and empirical grounds, the considerations raised here lend credence to the view that graphs are a uniquely powerful means of discovering, interpreting, and promulgating scientific findings. Yet graphs are a resource whose distribution is remarkably uneven, both across disciplines and within psychology. The question that naturally arises in consequence is whether psychologists should seek to emulate the harder sciences by adopting the graphical practices that are so characteristic of those fields. Mindful of the spotty history of schemes to upgrade psychology's status by importing the trappings of physical science—whether through appeals to operationism or calls for the adoption of paradigms—we are hesitant to draw blanket conclusions in this regard. After all, much of the important work in recent psychology (e.g., Fox & Prilleltensky, 1997; Graumann & Gergen, 1996; Miller, 1992) has been of a nonempirical nature, drawing on styles of analysis from softer disciplines such as discourse analysis, critical theory, and philosophy. As Laudan (1977) has argued, progress in science often comes from attending to conceptual problems rather than to empirical ones, and it certainly behooves psychologists to maintain self-critical

[4] If differences in graph use cannot readily be attributed to the degree of quantification of fields, it remains possible that graph use is related to a different global factor, namely, the degree to which researchers in various fields use visual devices in general. The possibility that graphism is an offshoot of a more general visuality of hard-science subcultures—a possibility not incompatible with Latour's emphasis on visual displays—is suggested by recent work on the importance in science of nongraph visual displays, such as maps, photographs, instrument printouts, and diagrams (Butler, 1993; Cheng & Simon, 1995; Golinski, 1998). Accordingly, we also recorded data from our sample of articles on the use of nongraph displays. Such displays were used much less often than either graphs or tables were, and their use showed no systematic relationship to levels of rated hardness. It remains unclear whether the editorial practices of specific journals discourage the use of visual displays (including graphs) because of production expense or other reasons (see Kruskal, 1978; Wainer & Thissen, 1981). In any case, the restriction of our survey to APA journals was motivated by a desire to control for any such biases at the level of the publishing organization.

vigilance about the conceptual and ideological aspects of their field. For this reason, graphism is not for everyone, even if its benefits would be welcomed by many others.

What remains clear is that psychologists, even the more empirically oriented, do not make use of graphical resources as fully as they could. According to one commentator, "psychologists continue to be remarkably unadventurous and inept in their use of graphics" (Costall, 1998, p. 290), and others have noted that "the use of graphics by psychologists has lagged far behind their use of elegant statistical procedures" (Wainer & Thissen, 1981, p. 236). Such reticence about the use of graphs has a larger history of its own. With its logocentric bias, Western culture has traditionally favored the use of words, logic, and the formalisms of mathematics over the use of visual images, which have long been suspected of misleading the mind by appealing to the senses rather than to reason. One result is the common attitude that "it is not the work of the scientist to draw little pictures" (Wainer & Thissen, 1981, p. 236), and even professional statisticians have been known to exhibit a "contagious snobbery" against graphs (Kruskal, 1978, p. 144). The avoidance of graphs may be especially prevalent among soft scientists who rely heavily on complex multivariate statistics, perhaps in the mistaken belief that multivariate data are not amenable to graphical depiction (Cleveland, 1993; Jacoby, 1998). But regardless of the reasons for aversion to graphs, such attitudes are difficult to sustain in an age when the technologies of data visualization are rapidly expanding and being applied to the increasingly large data sets made possible by electronic storage media. The benefits of visuality have never been lost on natural scientists, who have long understood that "graphs have particular affordances that other forms of representations such as language do not have" (Roth, Bowen, & McGinn, 1999, p. 989). When Giere (1988) asked a nuclear physicist why statistical tests for goodness of fit are rarely used in physics, the reply was that "more kinds of data can be assimilated by the eye and the brain in the form of a graph than can be captured with χ^2" (p. 190; see also Meehl, 1978).

Because the uses of graphs are many and extend throughout the research process (Smith et al., 2000), the potential benefits of graphism for psychologists are not easily summarized. But the utility of graphs begins early in the process. Even at the stage of planning research, the practice of graphing expected results can help clarify their relation to previous findings and to one's own and competing hypotheses (Machado & Silva, 1998; McGuire, 1989). Such preliminary visualization can also lead to the rethinking of dependent variables before the work of data collection is expended (as when floor or ceiling effects might obscure potential findings of interest) and can encourage the systematic varying of factors beyond the simple 2×2 designs that often hide important nonlinearities and subtle patterns of interaction. At the subsequent stage of assessing data for its credibility and coherence, synoptic graphs can facilitate comparisons of findings across alternative measures (a test of their robustness) and between present and previous results, encouraging the practice of replication by providing visual assessments of congruity more sensitive than the all-or-none decisions of statistical hypothesis tests. Results passing these initial appraisals of stability can then be further stabilized by being transported to meetings, where other scientists can critically examine them, negotiate their meaning, and be recruited to endorsing their facticity. At any stage in the process, graphs can also reveal the unexpected (Tukey, 1977), drawing attention to novel empirical relationships that would go undetected by standard inferential statistics. And when the research process culminates in publication, graphs can make a difference in how effectively results are disseminated, digested, and put to use. In his study of the fate of a large sample of psychology articles, Lindsey (1978) found that graph use was one of the best predictors of the rate at which the articles were cited in the literature, a finding that coheres with Latour's (1990) reflections on the rhetorical power of visual data.

In an interview with the late Herbert Simon, Baars (1986) asked, "What constitutes persuasive evidence in science, and particularly in psychology?" Simon replied, "Big qualitative phenomena that are loud and clear, that you can talk about without statistical significance tests" (p. 376). In the Latourian scheme of things, persuasive evidence of the loud-and-clear kind is exactly what graphs can provide, an observation that may help explain why the harder fields of science, with their highly visual orientation, enjoy well-stabilized bases of fact despite making less use of inferential statistics. Historically, many of psychology's most enduring and best stabilized findings—ones that still decorate the pages of its textbooks—have been cast in the form of graphical displays, depicting relationships arrived at without the use of inferential statistics. Among these are Fechner's law, Ebbinghaus's forgetting curves, the Yerkes–Dodson law, Stevens's power law, and Skinner's schedule-induced patterns of operant behavior—all findings that were discovered and promulgated without benefaction of *p* values. With the advent and rapid spread of inferential statistics in psychology (Rucci & Tweney, 1980), the use of graphical methods entered a period of stagnation. Although competence in statistical methods still remains more widespread than graphical competence, recent developments point to a revival of "graphicacy," construed as a set of crucial graphical skills analogous to literacy or numeracy (Wainer, 1980; see review in Wainer & Velleman, 2000). These developments also show that the evolving technologies of graphing are no less at home in soft-science domains than in laboratory settings (Wainer, 1997; Wilkinson, 1999). Modern graphing techniques exist for data of all levels of measurement, sample size, and dimensionality, ranging from simple univariate measures to complex multivariate data. And they can be applied to raw data or derived measures, regardless of their site of origin in the laboratory, field, or clinic.

In a discussion of Latourian theory and its ramifications for collective understanding in science, Roth and McGinn (1997) have written that

Graphs are central to interactions among scientists. Graphs constitute a shared interactional space that facilitates communication because of their calibrating effect on what can be taken as shared, and what has to be negotiated when it becomes obvious that it cannot be taken as shared. Thus, graphs are not only tasks to be accomplished through talk, but they also make talk meaningful. (p. 99)

Few psychologists would dispute the importance of meaningful shared talk for building bridges across psychology's scattered subfields (Anastasi, 1995). But to the extent that shared talk is graph-mediated talk, the uneven distribution of graphical practices across subfields—along with their power to create shared interactional space—threatens to pose costly barriers to fruitful interchange. The potentially divisive effects of differential reliance on visual inscriptions are more than a mere possibility. As recounted by Dewsbury and Bolles (1995), the splitting off of the Psychonomic Society from APA in 1959 was largely fueled by a ban imposed by APA that year on the use of slides at its annual convention. William Estes, who refused to forgo graphs for his presidential address to Division 3, was forced to recreate them on large poster boards and transport them to the convention, over a distance of some 2,000 miles, on the roof of his station wagon.

Psychologists may have little reason to hope for the sort of theoretical unification that comes from possessing a shared paradigm, but they can at least strive to cultivate practices that beget common rhetorical space. Paradigms are the remote endpoints of science—rarefied, elusive, and maybe even mythical (Leahey, 1992). Graphical practices are the stuff of everyday science—concrete, teachable, and learnable. Unlike paradigms, graphicacy is within reach. In the spirit of psychologists' ongoing quest to reflexively understand their own knowledge-construction practices, this article has presented graphs about graphs (and even multipanel graphs about multipanel graphs) to reveal otherwise invisible patterns in the rich matrix of investigational practices that collectively define psychologists' work. By heightening awareness of discrepancies in the distribution of some crucial visual resources, we hope to encourage psychologists to enrich their conversations, at least their more scientific ones, with increasing amounts of graph talk.

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