6 THEORETICAL INTEGRATION IN EXPERIMENTAL REPORTS IN TWENTIETH-CENTURY PHYSICS

SPECTROSCOPIC ARTICLES IN *PHYSICAL REVIEW,* 1893–1980

The activity of twentieth-century physics is already well situated in developed institutions of social, communicative, and empirical practice that help shape the daily life and long term direction of the field. As Leslie White has pointed out, established cultures contain vectors shaping future developments, for every institution embodies a form of life and establishes the means for carrying forth that life.

In the last several chapters we have seen how by the end of the eighteenth century many features of the institutions of communication had emerged—in the regularized form of published communications, in the regularized ways of producing and receiving these forms, and in the elaborated social organization in which such communications took place. The practices of criticism and argument that had developed in agonistic competition over accounts of particular events and generalized patterns of events took on regular shapes. Particular literary forms, casting representations in certain detailed forms and necessitating certain practical empirical work for their production, were shaped for audiences adopting certain roles within the elaborating social system. Individual texts, realizing and further developing these literary forms, were produced and received by individuals enmeshed in common understandings and experience constituted by participation in the evolving community. Knowledge claims put forth in these texts were thus highly contextualized linguistic products, the printed trace of complex systematic activities.

The nineteenth century saw many new developments in institutions of communication, social organization, and the empirical practice of science in Europe and, nascently, the Americas. To carry this story into the nineteenth century is an overwhelmingly difficult task as disciplines proliferated and grew distant from each other, each developing its own set of institutions and practices. Communications forums increased as well and developed differing communications dynamics, with major consequences for literary form and social organization. I make no attempt here to construct any detailed, researched account of developments in the nineteenth century, which I leave entirely to future studies. Comparisons of eighteenth-century and current practices (see pages 78–79 and 126–27), however, strongly suggest that major changes occurred in the nineteenth century in the way scientific texts referred to and relied on each other. The emergence of modern citation practices is the most visible, but not necessarily the most fundamental, product of the development of implicit and explicit intertextuality in nineteenth-century scientific communication. Studies of nineteenth-century scientific writing would do well to take on the question of changing institutions of intertextuality.

Rather than take on the immense job of a comprehensive account of the complex social, linguistic, and research networks that draw disciplines more tightly together internally and separate them from each other, I will look at developments within a limited region once these differentiations have taken place.[1] In looking at the changing forms of the experimental report within twentieth-century physics, and more especially spectroscopy, I will be examining how the increasing prominence of an overriding and integrating theory helps reshape textual form and bind texts even more closely to each other. In the two chapters afterward, I will examine how the integrated discussion and communal endeavor of modern physics shapes the individual's activity in writing and reading texts.

1. This is not to suggest that important interdisciplinary links may not be forged over both phenomena and theories. Although different specialties may look at the same object or phenomenon from different perspectives and with different motivating questions, accounts created in one specialty may have strong consequences for another specialty, witness such a celebrated example as the implications of Watson and Crick's molecular biology discovery for genetics, because the account of the DNA molecule offered the mechanism for the carrying of genetic information. Similarly, a theory developed around a narrow question may turn out to have greater power that carries across the work of many specialties, witness the celebrated example of quantum theory's origin in certain specific problems in thermodynamics.

Linguistic Code and Social Agon

Although here I discuss linguistic forms as evolving parts of the ongoing activity of a community, previous examinations of scientific language have tended to reify the highly elaborated linguistic forms of contemporary science into stable and independent textual structures. Linguistic studies of scientific language as a sublanguage (Kittredge and Lehrberger) or a special register (Crystal and Davy) consisting of particular lexical items (Savory; Hogben), syntactic forms (Huddleston; Lee; Gopnik) and organizational units (Meyer) treat scientific language as an independent system, to be learned as classical Latin or any codified school language is learned.[2] Indeed textbooks in scientific writing contain highly elaborated models of linguistic forms for students to follow. As a socializing and educational practice there may be some warrant for this attitude, despite significant pedagogical dangers in freezing forms and isolating them from practice (more of this in chapter 12). In any event there is some need for neophytes to be introduced to the current means of communication, to learn the ways of formulating statements appropriate to the community they wish to enter. Such an introduction both provides a repertoire and aids social acceptance of statements framed according to current habits.

However, such an approach to scientific language reduces its use to a matter of following prescriptions and avoiding prohibitions. Such a view isolates writing from the larger processes of formulation and interaction by making it merely an editing-for-propriety process, rather than a complex social event. Such a view hides the motive for writing, the larger part of the process of creating formulations, and the rhetorical import of these formulations.

Yet, in the last few chapters, we have seen how the forms of scientific representation emerged simultaneously and dialectically with the activity of science and the social structure of the scientific community. Features of the experimental article developed as part of an agonistic social activity, arguing over experienced events. The experience is shaped by the argument just as the arguments exploit the experience in a public linguistic forum.

Studies of scientific discourse coming from sociologists of science have indeed emphasized the agonistic force of language in the competi-

2. John Swales's analysis of article introductions offers a welcome exception to this general treatment of scientific writing as a disembodied code. Here and in consequent articles he considers the organization of article introductions as a solution to the rhetorical problem of establishing a place for one's work within a relevant literature.

tion over claims, power, and the satisfaction of interests. These studies have established that authors control the language and presentations of their papers so as to present their work in the most favorable light, so as to advance the acceptance of their own work, and to further their interests as scientists. Most aspects of the article, even the presentation of data, are open to forms of literary control, with the writers particularly concerned with persuading readers of validity and importance of their work.[3]

By representing scientific argument as an unbounded free-play of competing interests, however, these studies have erred in the opposite direction. They have ignored the historically evolving structure of scientific communications which has embodied and defined the evolving nature of the competition. While each participant in pursuit of individual goals may seek whatever resources are available and may bend the current rules and practices to personal advantage, those rules and practices and the recognized resources embody and shape the communal activity, evolve over time, and contain inherent goals and vectors.

Typically, most of the sociological studies of scientific discourse treat the previous literature as a persuasive resource, a validating set of scriptures to be effectively arrayed through references, but these studies do not consider how this prior literature helps define the current work. The sociological study of scientific texts, in an attempt to free itself of positivist historical whiggishness, which finds in scientific papers the march toward rational truth, has tended to cut itself off from the shaping effects of history even as it finds each separate moment indexically intertwined with a local sociohistorical context. Curiously, this leads to an assumed uniformity of freedom for the scientific writer, throughout history and in all situations, so that case materials from all times and across all disciplines are treated equally as sources for generalizations.[4]

3. Latour and Woolgar in *Laboratory Life* were the first to explicitly discuss the scientific text as making a move on an agonistic field, but also consistent with that view are Collins and Pinch, *The Social Construction of Extraordinary Science;* Gilbert, "Referencing as Persuasion," and "The Transformation of Research Findings into Scientific Knowledge"; Gilbert and Mulkay, *Opening Pandora's Box;* Woolgar, "Discovery: Logic and Sequence in a Scientific Text"; Gusfield, "The Literary Rhetoric of Science"; Knorr, "Producing and Reproducing Knowledge"; Knorr-Cetina, "Tinkering Toward Success," and *The Manufacture of Knowledge;* Latour, "Essai de Science-Fabrication"; Latour and Fabbri, "La Rhetorique de la Science"; Law and Williams, "Putting Facts Together"; Yearley, "Textual Persuasion."

4. There have been significant exceptions to this ahistoric tendency, most notably Martin Rudwick's exemplary detailed study *The Great Devonian Controversy,* which traces how evolving claims in an early nineteenth-century geological controversy were shaped by existing forums and forms of communication, the evolving state of the debate

Theory as a Textually Integrating Force

The following examination of experimental articles in physics since the late nineteenth century indicates how texts have become embedded in a web of common theory, a structuring force even more powerful than the web of citation and cross references (elaborated in the citation studies literature).[5] That common theory has become an extremely strong force in structuring articles and binding articles to each other. Acceptance of common theory not only creates common interests among the adherents, and a massive edifice to be elaborated by many practitioners, it binds together wide ranges of empirical experience, gathered by many different people at different moments engaged in different activities. The theory points them to certain kinds of experiences, suggests the appropriate means of designing and interpreting empirical events, and allows results to be harmonized with the results and ideas of others. Thus, over the period and within the range of texts examined below, theory has come to permeate writing in physics.

Just as the argumentative structure in Book 1 of the *Opticks* gave a coherence, force, and certainty of meaning and reference to Newton's claims, quantum theory helps place and stabilize claims and observations in contemporary spectroscopy. Thus one would expect that the discipline would find many ways to tie the texts in with the prevailing theory. Unlike Newton's presentation, however, the theoretical construct and its elaboration is the work of many hands. Thus the development of an integrated discourse cannot rely on a single Euclid-like exposition of a unified system from first principles. More elaborate and flexible linguistic means must be developed to permit communal construction of the unifying system.

This chapter, in particular, looks at the changing features of experimental reports appearing in the *Physical Review (PR)* from its founding in 1893 until 1980.[6] This period marks the rise of American physics from backwardness to world dominance (see Kevles), reflected by the journal's rise from a local, university organ to the primary international journal of physics.

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and the evidence gathered and represented in the literature. Susan Cozzen's study "The Life History of a Knowledge Claim" examines the historical process by which texts become embedded in the literature of a field.

5. The literature on citation studies is reviewed in Cozzens, "Taking the Measure of Science."

6. Extensive background on the development of *Physical Review* appears in Merton and Zuckerman, "Patterns of Evaluation in Science" and in Physics Survey Committee, *Physics in Perspective IIB*.

Further, this period marks the virtual disappearance of the book as a way of presenting new results in physics. Early volumes of *PR* devoted as much as one-sixth of their pages to reviews of new books, including new contributions to the research front as well as textbooks. By 1910, however, new books were only listed, not reviewed; after a short revival of reviews in the 1920s, all mention of new books in physics vanished in the early 1930s. By that time research physics meant journal physics exclusively, with the article and shorter note (or letter) as the standard genres. In 1929 letters were added as a regular feature of *PR* until they were split into the separate journal, *Physical Review Letters,* in 1958. This study, however, will attend only to full articles, eliminating all texts placed in sections identifying them as notes, letters, minor contributions, or the like. One other regular feature of the journal from its founding through the 1950s was conference reports, including abstracts of delivered papers; these reports and abstracts also will not be studied here.

Finally, the period from 1893 to 1980 contains the introduction and establishment of the new physics and the enormous growth in the amount of physics research. Radioactivity was discovered in 1895; Einstein's first paper on relativity was published in 1905; Bohr's trilogy on the structure of hydrogen appeared in 1913; and the main features of quantum mechanics were settled with the publication of DeBroglie's and Schrödinger's equations in 1925 and 1926. The exponential growth of physics in this century has been demonstrated by Price; this growth can also be seen in the increase of equivalent words appearing annually in *PR.*[7]

Thus the period examined and the research site within American physics help highlight the impact of the development of an integrated and extensive professional community on the discourse of the field, although it may distort the international picture somewhat by hiding developments in nineteenth-century European physics. Some of the developments we will see in this chapter have likely been anticipated or at least prepared for in Europe. Further, differing events and relations within nineteenth-century European physics may have led to textual

7. Equivalent words are calculated by assuming the entire page to be filled with printed words with the size and spacing used throughout the main body of the article; this method helps incorporate changing use of equations, illustrations and other nonword features, while taking into account changing typographical presentation. In the first year of publication 190,000 equivalent words appeared in *Physical Review;* in 1900, 260,000; in 1910, 600,000; in 1920, 570,000; in 1930, 1,700,000; in 1940, 1,800,000; in 1950, 4,200,000; in 1960, 8,400,000; in 1970, 29,000,000; and in 1980, 30,000,000.

developments not reflected in the more recent American case. Such observations, however, await further research.

Methodological Problems and Selection of Materials

The attempt to characterize a large body of writing presents enormous problems, especially when the examination is carried out by a single researcher. The kind of analysis generally considered most revealing about the nature, organization, function, and style of a text is the traditional method of literary criticism: close analytical reading. The method is not only time-consuming, it is particularistic, revealing in detail the special qualities of individual texts. The method tends to militate against generalization and to produce masses of incommensurable findings. On the other hand, statistical methods, such as those adopted in computer studies of style, do provide comparable data open to generalization. Moreover, certain statistical comparisons were available for this study that were not available for the study of earlier *Philosophical Transactions* because the genre had by the end of the nineteenth century stabilized in many significant ways. The stabilization of the genre helps create countable and comparable features as well as providing a framework for the interpretation of the results of such counting. However, statistical counts provide only information about the most surface features of the text (at least at this stage of methodological development). My strategy to contend with this dilemma is to employ a mixture of methods—using statistics to indicate gross patterns or trends but using close analytical reading to explore the finer texture, the meaning and the implications of those trends. The statistics are to indicate that something is happening, and the close readings are to find out what that something is.

As implied earlier, the indicators and analytical readings are aimed at establishing gross trends in style and genre, as suited to the study of a historical body of articles not discussing the same immediate problem. Other analytical tools and different kinds of selections of articles would, of course, tell more about the detailed interplay among specific articles and authors as they use the conventions of style and genre revealed here to pursue individual interests, and/or to resolve particular issues of knowledge.

Given my limited resources, both the statistical and close reading analyses had to be carried out on limited selections of material, too limited to warrant the statistical designation of samples. I have tried to avoid making strong inferences where the numbers are small, but the entire endeavor must be granted some statistical charity until more comprehensive studies can be carried out.

For different levels of analysis, I have used three different selections of material. For the measure of article length, I have considered all articles through 1900 and every fifth year thereafter through 1950; since 1955, because of the increasing volume of annual publication, the data are limited to the first few issues, totalling 3,000–6,000 pages, of each fifth year.

For analysis of references, graphic features, organization, and mode of argument, I have examined a total of forty experimental articles reporting spectroscopy as a primary technique and appearing in 1893, 1900, and every ten years thereafter through 1980. If fewer than three appropriate articles appear in any year, as in 1900, articles from the next year are also included; if more than six appear, as in recent years, only those from the earliest months are used.

Finally, for sentence-level analysis, a subset of the spectroscopic articles is used, comprised of all the selections from 1893–95, 1920, 1950, and 1980—totalling seventeen in all. Appendix 1 gives the bibliographical citations for articles explicitly discussed, which will be identified in the text by year of publication and author's initials (e.g., 1893-EFN).

Given the variety, changes, and proliferation of specialties in physics over the life of the *PR*, it seemed advisable, except for the overall measure of article length, to limit the texts examined to a single specialty. Of all the specialties in physics, spectroscopy has been the most stable over the period examined. To stabilize the selection further, I have eliminated work based on the recent innovations of electron spectroscopy and the application of spectroscopic technique to the study of nuclear events, both of which have opened up some new directions for the field. I have also eliminated purely theoretical articles, for, in this specialty, they too are a phenomenon of the last half century, in the wake of quantum mechanics; the theoretical components of experimental articles will, however, remain part of the examination. Astronomical spectroscopy is a different field.

The major empirical discoveries of this narrowed specialty (what we might now call "the experimental study of the electromagnetic spectra of orbital events") were made before, or just at the time of, the founding of *PR*. Fraunhöfer lines were discovered in 1802, and through the middle of the century variations in lines for different substances were noted. Techniques and standards were refined until, in 1896, Zeeman discovered the fine-splitting of lines under a magnetic field. On the theoretical side, Kirchoff proposed in 1859 that absorption spectra were the same as emission spectra; between 1885 and 1890 equations were proposed to account for the distribution of lines, most notably by Balmer, Kayser, Runge, and Rydberg. Until the emergence of quantum theory, however, no comprehensive theory accounted for spectral lines, which by then had been observed for over a century.

The earliest articles on spectroscopy in *PR* already incorporated what were to remain the primary purposes of spectroscopic research: to measure the lines of different substances under different conditions, to account for the distribution of these lines, and to use the lines to help describe or understand unusual substances or phenomena. Thus, in the first two years, articles appeared reporting on the infra-red spectra of common substances, testing whether an equation predicted a set of lines, and using spectroscopy to investigate limelight. Since then techniques have changed (resonating lasers and electromagnetic counters tuned to narrow reception channels have replaced the prism or grating and photographic plate as measuring devices) and changes in surrounding knowledge have changed ideas of what lines would be interesting to study; but the basic tasks remain the same. Articles in 1980 still reported on the lines of various substances under various conditions, accounted for those lines by assigning starting and finishing quantum states, and used lines to measure and understand dense plasmas. This stability of basic activity simplifies the task of analyzing changes in language and modes of argumentation.

The limitation of material does, unfortunately, leave open several questions about the generality of the findings. First, the narrowing to experimental articles eliminates consideration of developments in the purely theoretical article, of increasing significance in recent decades. Second, without a wider cross-section of material we can only speculate on the extent and manner in which the writing in spectroscopy is typical of writing in the other specialties of physics. The stability of the specialty is in itself idiosyncratic in twentieth-century physics. Other specialties may have different intellectual or social structures, calling forth different kinds of argumentation; even the age or rapidity of change within a specialty may affect discourse patterns. On the other hand, given the stability of spectroscopy, the discourse changes may suggest the more general drift of the entire discipline, freed from the intricacies of specialty change. In any event, the problems in studying more rapidly changing specialties, many of which did not exist in anything like the modern form until recently, make such studies difficult, at least until maps of some simpler specialties are drawn to serve as comparative models. Finally, there is the problem of attempting to generalize from an American journal to all of international physics. In particular, the early features of articles in *PR* may be as much a consequence of the backwardness of American physics as of the general discourse patterns of international physics. Today, *PR* clearly represents the standard in international physics, but when this became established is not clearly known. Again, only a wider cross-section of material, including historical examination of European journals, will resolve this issue. Such comparisons may even reveal abiding differences in national style. The current study, nevertheless, as a first foray into the description and analysis of changes in the scientific article, will at least provide one reference point for later comparisons.

Results

ARTICLE LENGTH

A comparison of the lengths of *PR* articles through the years suggests, as a first approximation, some of the changes that have occurred (see figure 6.1). From 1893 until 1900, the average length of an article dropped from about 7,200 equivalent words to about 4,500, then immediately began to rise to a secondary peak of about 5,700 in 1920. The average then dropped to a bottom of about 4,600 words for ten years from 1925 to 1935, before beginning a sharp and steady rise continuing to the present, with a 1980 average of over 10,000 equivalent words. The splitting of the line in 1970 reflects the splitting of the journal into four sections: A, General Physics; B, Condensed Matter (Solid State); C, Nuclear; and D, Particles and Fields.

This graph contradicts the commonplace that in the nineteenth-century scientific writing was more expansive, but in this century articles have become increasingly compact under several pressures, not the least of which has been publication costs. The consistent expansion through the middle and latter part of this century confirms Abt's survey of astronomical journals from 1910 to 1980, and the more limited statistics on *PR* presented in the Bromley Report (Physics Survey Committee).

Figure 6.1, moreover, bears little relation to the major editorial events and policy changes of *PR*. When the journal changed sponsorship from Cornell University to the American Physical Society in 1913, an editorial claimed that recent more stringent editing had kept lengths down and made the sponsorship shift economically feasible; in fact, the major

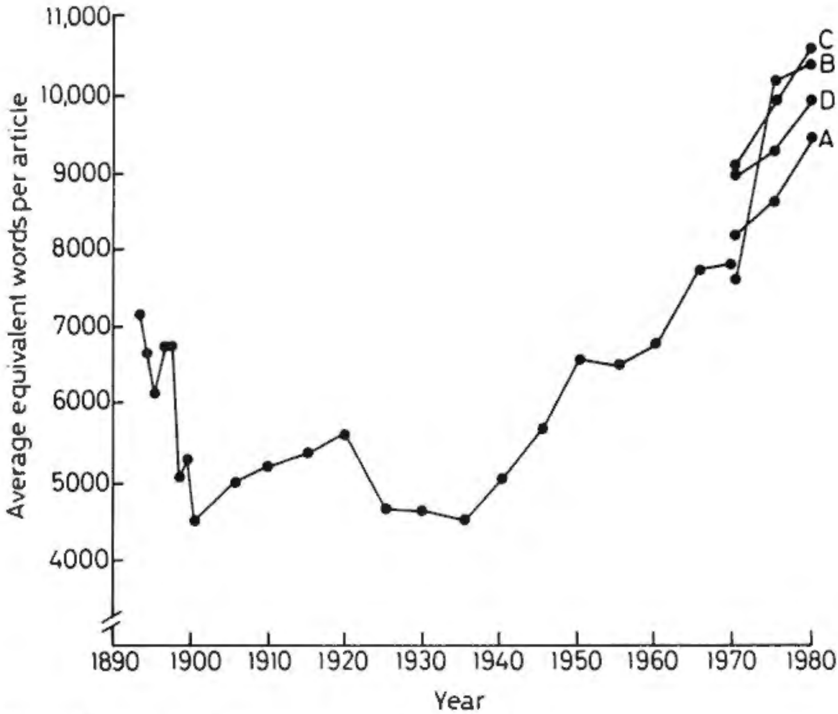

Figure 6.1. Average Length of Article in *Physical Review*

drop in article length had ended thirteen years previously, and article length was rising at the time. However, a decrease in total pages, from about 1,500 pages in 1910 to about 1,050 pages in 1915, had been achieved by a decrease in the number of articles published (from 104 to 83), and by a 25 percent increase in the number of words per page. Similarly, neither the page charge (instituted in 1930), nor the letters section (instituted in 1929), had any noticeable effect; nor did the splitting of letters into a separate journal in 1958; nor did the splitting of the journal into four sections in 1970. In the last two cases, the length simply continued an ongoing rapid rise, apparently moved by other forces.

Similarly, changes of editor seem to have had, at most, a marginal effect on article length. Turnovers of the editorship occurred in 1913, 1923, 1926, 1950, 1951, and 1975. The 1913 and 1975 turnovers do not correspond to any changes in the graph; the turnovers in the mid-1920s and early 1950s do correspond to temporary flattenings in the length curve, but such flattenings are only small adjustments to other, larger, longterm trends.

The data analyzed in the remainder of this chapter will suggest other, more substantial reasons for the length changes, related to intellectual changes in the discipline. The lengthy articles of the mid-1890s will be seen to reflect a looseness of style, a focuslessness of argument, and a lack of compact technical vocabulary. By the turn of the century, articles will be seen to gain focus on particular issues of theory, becoming more selective in content and more purposeful in organization. The radical theories of the new physics will be shown to be associated with a more tentative, contemplative style, reevaluating and adjusting theories. Once the most confusing theoretical issues had been sorted out in the late 1920s, increasing length will be shown to be related to increasing knowledge and theoretical elaboration, with articles becoming more focused and compact, but relying on increasing amounts of background and contextual knowledge so that length and density rise together.

REFERENCES

A strong indicator of the reliance of a text on background and contextual knowledge is the use of explicit references to prior literature. The amount, pattern and function of references have changed significantly in the articles examined, suggesting the increasing embedding of arguments in the web of the literature of the field. Figure 6.2 presents the average number of sources referred to in the decade-by-decade selection of spectroscopy articles. Note the rapid decline over the first twenty years, and then the generally consistent rise until the present.

A detailed look at these references reveals what happened.[8] In the early years, references are used rather generally in the text of the article; they do not refer to a specific finding, nor identify a specific relation to the current work. Serving as a roll-call of previous work in the general area, references congregate at the beginning of the article, never to be raised in a significant way in the course of the argument—except perhaps in relation to methods and apparatus. For example, 1895-EM contains eleven references in the first quarter of the article, one reference in the second quarter, and none thereafter. In the same spirit, 1893-EFN, the first article of the premier issue, begins:

> Within a few years the study of obscure radiation has been greatly advanced by systematic inquiry into the laws of disper-

8. I have followed the procedure of examining references within the context of the entire article, as recommended by Chubin and Moitra. I use a fuller descriptive technique, rather than the kind of formal typology proposed by Chubin and Moitra or Moravcsik and Murugesan, although the description here does rest on concepts of reference use, as considered in both articles. The description also rests in part on ideas from H. Small, "Cited Documents as Concept Symbols," and S. Cozzens, "Life History."

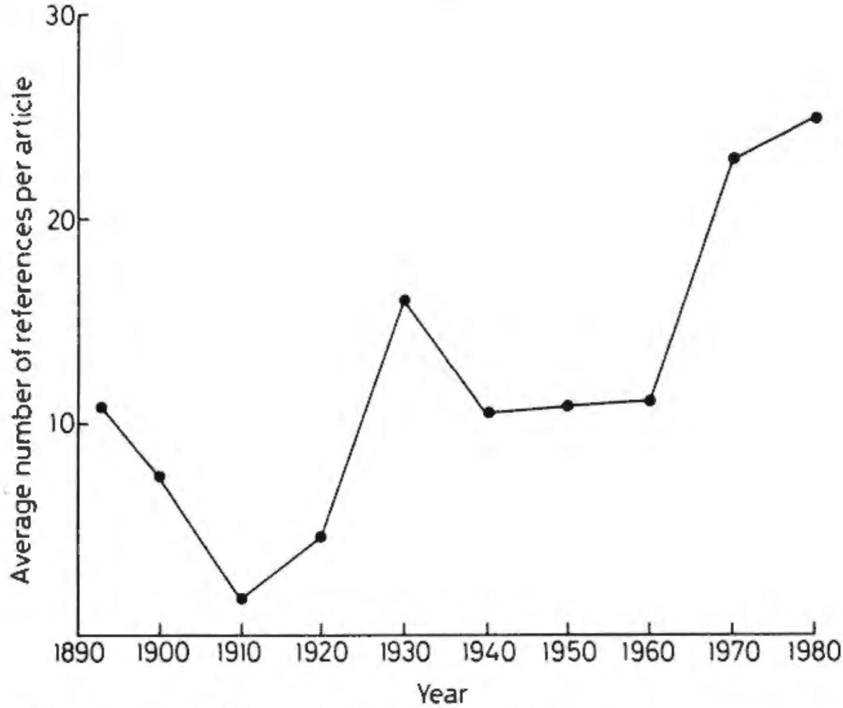

Figure 6.2. Average References per Spectroscopic Article

> sion of the infra-red rays by Langley,[a] Rubens,[b] Rubens and Snow,[c] and others. Along with this advancement has come the more extended study of the absorption in this region. The absorption of atmospheric gases has been studied by Langley[a] and by Angstrom.[d] Angstrom[e] has made a study of the absorption of certain vapors in relation to the absorption of the same substances in the liquid state, and the absorption of a number of liquids and solids has been investigated by Rubens.[f]

The references here serve to establish a tradition the author is working in, but do little to define a specific context of knowledge, theory or problems that circumscribe the current task. The author only promises to do more of the same:

> In the present investigation, the object of which was to extend this line of research, the substances studied were . . .

The lack of concern with dating references, and the age of the references that are dated, further weaken the sense of a coherent, moving research front. In both 1893–95 and 1900–1901, 52 percent of the references are undated, and only about 30 percent are dated six years or less from the article's publication.

By 1910, the number of references per article has decreased dramatically to only 1.5, and the few references are dated and of recent vintage, suggesting immediate relevance to the work at hand. In this spirit, 1920-CDC/DC begins:

> A knowledge of the relation between the spectrum of a substance and that of its isotope is important in that it may throw further light on the structure of the atom. Some work along this line has been done. Aronberg,[a] working with a grating spectrograph has reached the conclusion that the wave-length of the line λ 4058 is greater by 0.0043 A. for lead of radioactive origin than it is for ordinary lead. The work of Aronberg has been corroborated by Merton,[b] working with a Fabry and Perot *étalon*.

The passage continues with a discussion of the work of Duane and Shimizu, and of Siegbahn and Stenstrom, in the same spirit: these are specific findings of concrete relevance for the current investigation. Furthermore, all four references are less than four years old.

Even as the number of references per article has increased over the last sixty years, the specific relevance for the work at hand and the lengthy discussion have increased, with the result that new work appears increasingly embedded in the literature.[9] For example, in 1980-KHF et al., the extensive discussion of results is structured around comparison with the results and models presented elsewhere in the literature:

> The strong 'structures' on the lines resemble those predicted by Oks and Sholin.[a] As described there, one typically finds a valley with one hill on each side. However, the strongest 'structures' are not at spectral positions corresponding to the plasma resonance but rather at positions between $\frac{1}{4}\,\omega_{pe}$ and $\frac{1}{2}\,\omega_{pe}$. The calculations of Oks and Sholin predict similar structures not only at the resonance frequency but also at some harmonics and subharmonics, i.e., at $\frac{1}{2}\,n\omega_{pe}$ with $1 \le n \le 8$; $n\,/ = 7$ for $H\alpha$. The predicted positions are marked in Fig. A. Because of the

9. The historical depth of the references did increase in the World War II period, with only 53 percent of references six or fewer years old in 1940 and only 37 percent in 1950, indicating the disturbing effect of the war on research. More recently there has been a like stretching out of references, with 40 percent six or fewer years in 1970, and 61 percent in 1980, indicating perhaps the maturity or lack of "heat" in the field.

> uncertainty in the density determination and therefore the value of ω_{pe}, we cannot decide at present whether the observed line contour corresponds indeed to the model of Oks and Sholin.

Note the great length of the discussion, the specificity of the summary, the quantitative comparison (through the figure) between the reference and the work at hand, the attempt to evaluate the correspondence, and a discussion of the difficulties in carrying out the comparison. The work of Oks and Sholin is made an integral part of the intellectual content of the new article. References, as well, have tended to spread throughout the article, so that every stage of the argument relies on the work of others. 1980-SJR, for example, uses fifteen references in the first quarter of the article, eleven in the second quarter, eleven in the third, and three in the last.

Analysis of references then suggests a loose cognitive structure in the early years, with one piece of work claiming only general connection with earlier work. In the early part of the twentieth century, tighter standards of relevance developed, bringing work into greater coordination. Throughout the remainder of the century both the amount of relevant work for each article and the integration of references into the argument have increased. More references are being discussed in greater detail at more junctures throughout the article. This increasing discussion of sources is a factor in the growing length of the contemporary article, just as the deletion of the loose roll-call of forebears at the beginning of early articles was a factor in the decrease of length at the turn of the century.

SENTENCE LENGTH AND SYNTAX

Sentence length, on the other hand, has remained fairly stable: in 1893–95 it averaged 27.6 words per sentence; in 1920, 28.3; in 1950, 25.3; and in 1980, 23.7.[10] Sentences have also tended to remain generally simple in structure, averaging (in traditional grammatical terms) about 70 percent simple sentences, and 30 percent complex sentences, in all four time periods. Similarly, the types of phrases used to expand simple sentences, and the number of clauses used to develop complex sentences,

10. The sentence length, syntax, and word choice data were obtained from all the selected articles in 1893–95, 1920, 1950, and 1980. From each of the articles three to five passages for analysis were chosen, representing whichever of the following sections of the argument were present: introduction, theory, experimental, results, discussion/conclusion. The passages began at the beginning of each of the sections and ended either at the first sentence break after two hundred words were reached, or at the end of the section if it was under two hundred words in length.

show no significant changes over the period. These three levels of sentence stability suggest that neither changes in article length nor perceived changes in the "difficulty" of reading can be attributed to changes in sentence patterns or sentence style.[11]

The only significant syntactical change found is in the types of subordinate clauses used in complex sentences. The percentage of relative clauses decreases regularly and significantly through the period (1893–95, 54 percent of subordinate clauses; 1920, 47 percent; 1950, 37 percent; and 1980, 17 percent).[12] Such relative clauses simply modify a noun already present in the main clause, adding information or precision but not adding to intellectual complexity, as in this example from 1980-RAR et al.:

> The spectra thus obtained were found to be identical except for slight variations in relative peak intensities, which were attributed to lamp fluctuations and variations of the analyzer transmission.

Although the relative clause tells us more about the causes of the variations, the primary statement of the sentence (the essential identity of spectra) remains unaffected. On the other hand, noun clauses (presenting facts, claims, or observations that serve as nouns in the main clause), and subordinate clauses establishing temporal or causal relationships (using subordinating conjunctions such as "when," "because," or "if"), both increase regularly and consistently in percentage throughout the period. The percentage of noun clauses increases from 15 in 1893–95 to 33 in 1980, and the percentage of temporal and causal clauses rises from 31 to 50. Noun clauses can keep two thoughts in the air at the same time, as in 1980-KHF et al.:

> The analysis of the continuum intensity and of the optical thickness of the plasma column as well as the Schlieren measurements showed that plasmas with electron densities between 5×10^{17} and 7×10^{19} cm^{-3} can be reproduced rather reproducibly.

11. The data support neither of two related folk beliefs concerning contemporary scientific style: an increase of sentence complexity resulting from an influx of German-speaking scientists, and a loss of syntactic control resulting from the general loss of command of the English language. If anything, the data show a limited consistency with what is believed to be a general simplification and shortening of the English sentence in America over this century.

12. The data were limited to two-clause sentences to control for more complex syntactical relationships established in sentences of three or more clauses.

Similarly, the temporal and causal subordination puts two ideas or events in relation to one another, as in 1980-SJR:

> As the electric field was applied, the oscillator was simultaneously returned to within 10Hz of the shifted point of maximum slope.

Thus changes in subordinate clause types suggest increasing intellectual complexity, even while sentence length and syntactical complexity remain about the same.

WORD CHOICE

This tendency to expand intellectual complexity within unchanging linguistic complexity becomes more pronounced when we examine word choice. Most important are the words that fill the two main syntactic positions in the sentence: the subject and verb of the main clause. These two positions usually define the main meaning elements around which the rest of the sentence revolves, unless the main claim is hidden behind an empty phrase such as "there are" or "one can say that." Such empty phrases appear in only about 5 percent of the sentences examined.

Throughout the period, 70–79 percent of main clause subjects have been either names of objects (that is, apparatus, observed features, or objects presumed to exist in nature) or names of abstractions (that is, processes, qualities, or generalized terms), but the balance between the two has shifted from virtual equality in 1893–95 (36 percent objects, 34 percent abstractions) to a 1:3 ratio in 1980 (19 percent objects; 57 percent abstractions). That is to say, recent sentences are centered less on concrete descriptions and more on topics of theoretical significance. Thus the opening sentences of 1893-EM use the following concrete grammatical subjects: "fact," "substance," "plates," "turmalin." The opening sentences of 1980-RAR et al., on the other hand, use more abstract subjects: "excitation," "correlation," "ionization," "autoionization." The increasing abstraction of sentence subjects reinforces the impression of increasing content.

The main verb also has been conveying more substantial content over the years as the percentage of substantive active verbs has been increasing (from 16 percent in 1893–95 to 35 percent in 1980) and the percentage of reporting verbs has been decreasing (from 10 percent to 3 percent). Passive verbs and forms of the verb "to be" have remained equally important throughout the period, with passives accounting for almost half of all main clause verbs, and "to be" for about one quarter. The decrease in reporting verbs (for example, "Smith reports . . .") and increases in active verbs (for example, "temperature increases . . .") suggest that the finding or theory has increasingly been brought into the central grammatical position, while the publishing scientists have been given a back seat, thus adding density to the discussion and integrating source material into the continuity of the argument. The following two examples highlight this stylistic change. The opening section of 1895-EIN presents some findings with the aid of reporting verbs:

> In 1885, Messrs Siemens and Halske of Berlin published the results of measurements for the purpose of showing the superiority of the silver-grey surface obtained by treating filaments of glow-lamps by bringing the same to incandescence in an atmosphere consisting of volatile hydro-carbons. In the following year Mr Mortimer Evans described comparisons of the radiation from bright and black incandescent lamp filaments in which the superiority of the former was very clearly demonstrated.

In this chronological narrative, the point of theoretical interest remains obscure, as do the significances of the various details. What we most learn are the doings of scientists. In 1980-KF et al., two sentences pointedly summarize a large body of research with specific purpose for the work at hand by making the point of interest the grammatical subjects, and the relevance of those subjects the verbs (the first active, the second passive). The scientists have vanished to the footnotes.

> Laser techniques provide both an efficient population of highly excited states as well as a resolution frequently only limited by the radiative width of the excited state. Thus, Doppler-free two-photon spectroscopy,[a] quantum-beat spectroscopy,[b] level crossing,[c] rf resonance[d] and microwave resonance techniques[e] have been used for studies in sequences of D states, especially, but also P, F, and G states.

Thus changes in main clause verbs and nouns have made sentences more directed toward the argument, more active and denser.

A more general inspection of the vocabulary also indicates increases in the density of information and the theoretical meaning—that is, the embedding of meaning within particular bodies of knowledge and theory. These increases are evidenced by growth in the percentage of words having technical meanings (in 1893–95, 15 percent; in 1920, 14 percent; in 1950, 29 percent; in 1980, 32 percent). Consider the two passages quoted just above. In the passage from 1895-EIN, the first term with technical meaning is almost thirty words in, and most of the technical terms are not far removed from their then-common usage: "filaments," "glow-lamps," "incandescence," "atmosphere," "volatile," "hydro-carbons," "radiation." Only one term, "hydro-carbons," does not have a closely related common-use meaning. The terms do gain some specificity of meaning from the technical context, such as "filament," meaning not just a thin fiber, but one through which electric current is passed to produce heat and/or light. The terms also gain meaning from the accumulated work to perfect the incandescent lamp, and from existing electrical and chemical theory. The passage from 1980-KF et al., however, contains a higher number of technical terms, with meanings further removed from ordinary use. Not only do terms like "laser," "Doppler-free," "photon," "spectroscopy," "quantum-beat," "rf resonance," and "microwave" have their origin in scientific theory and practice, they incorporate large amounts of scientific knowledge in their definitions. In order to understand the terms with appropriate precision one must have substantial understanding of current physical theory and knowledge. Even terms with common-use meanings have highly specific, content-laden meanings in the context of the scientific article: "efficient population," "excited," "state," "radiative width," "level crossing," "sequences," "D, P, F and G states." Many of the meanings, in fact, derive rather directly from quantum theory.

One final lexical feature, the multiword noun phrase, has increased density and theoretical import. These phrases, sometimes hyphenated, combine words from common and technical vocabularies to create new terms of highly specific meaning. For example, the opening two paragraphs of 1980-KHF et al. contain such hybrids as "plasma spectroscopy," "electron densities," "free-bound continuum," "half-width," "line profiles," "mean particle-electric-field strength," "thermally excited longitudinal plasma waves," "collective wave field," "mean interparticle field," "current driven turbulence," and "thermal equilibrium." Such phrases are to be distinguished from ordinary adjective-noun clusters in that they modify not just by adding information, but by placing the object, event, or concept within a more specific framework of knowledge. An equivalent passage from 1893-EFN contains far fewer of these hybrids, and they tend to resemble more traditional nouns modified by adjectives: "atmospheric gases," "lamp-black," "potassium alum," "ammonium alum," "aluminum-iron alum," "fifty-volt Edison incandescent lamp." It should be remembered that from the time of Chaucer until the early part of this century, "alum" was a common term.

GRAPHIC FEATURES

Scientific articles contain, of course, more than running text: graphic features—drawings, graphs, tables, plates, and equations—interrupt the block of prose. They shift the argument into different symbolic media, but the decisions of when and where to employ them, how they should be designed and what information to include, are as much writing decisions as are word selection or organization. Here, as in other features already examined, we see the movement from early concreteness to recent abstraction, from early representations as ends in themselves and intelligible without extensive scientific knowledge, to recent issue-directed, interpretive arguments dependent on substantial disciplinary knowledge. To put it more concretely, a scan of articles of *PR*, series 1, volume 1, leaves a visual impression of detailed apparatus drawings and extensive tables of raw experimental data, while a scan of the journal of 1980 leaves a visual impression of extensive equations and schematized graphs.

Specifically, the decade-by-decade selection of spectroscopy articles contains, first, a decreasing use of apparatus drawings. Up to 1920, all but two of the selected articles had equipment illustrations—some realistic in representing the actual appearances of devices, others more schematic in representing only the essential optical features, but all directly representing the equipment employed. By 1930, however, fewer articles contained such illustrations, and those included tended to be abstract. Of the eleven articles examined from 1960, 1970 and 1980, only four had equipment diagrams, and all four were schematic representations of functions (functions being identified by word label), rather than representations of actual equipment.[13]

A more recent form of illustration is the schematic representation of quantum states and transitions hypothesized as present in the experiment at hand. Such illustrations first appeared in 1940 in one of four articles examined; in 1950 transition schematics appeared in two of six; in 1960, two of three; in 1970, one of three; and in 1980, two of five. Such diagrams, being specifications of quantum theory, are theory dependent, abstract, and interpretive (that is, at several removes from the raw data, and serving as explanations of those data).

Similarly, tables of results, originally presenting all results and often in raw form, become increasingly selective, summary, calculated, and focused with respect to theoretical importance. Tables become shorter

13. The detailed representation of novel apparatus has migrated to instrumentation journals, but the very separation of such materials from primary research reports signals that information about instrumentation advances is not considered of the same category as research findings.

and by 1980 appear in only two of the five articles examined. The burden of data presentation has increasingly been placed on graphs, especially since 1950, even though graphs were always present in substantial numbers. All of the 1980 articles, for example, display their data through graphs. Graphs, in addition to displaying data, show trends and allow comparison with other data and with theoretical predictions displayed on the same or neighboring graphs. In fact, all five of the 1980 articles examined incorporate some comparative features in the graphs, and four out of five compare results, theoretical values, and other relevant curves extensively—through multiple curves on single graphs, multipart graphs displaying different kinds of curves, and adjacent graphs (as many as eight at a time). The display of data has thus become more purposeful, interpretive, intellectually complex, and intertwined with the theoretical argument of the paper.

Finally, equations make more frequent and more prominent appearance in spectroscopic articles as the period progresses. The three articles examined from 1893 to 1895 contain no equations or mathematical expressions, while the five articles from 1980 contain forty-three lines of equations and expressions, not including those printed as part of the running text. The contrast would have been even more striking if theoretical articles were also considered. In the early years of *PR*, no purely theoretical article appeared on the topic of spectral lines; but since the establishment of quantum mechanics, they have abounded. It is not uncommon for recent theoretical articles to have twenty or more lines of equations and expressions per page. The appearance of equations is a clear indicator of the integration of theoretical explanation and prediction into the argument of the paper.

It is instructive to notice the difference in pattern of illustration change here from that observed in the *Transactions* in the earlier period. From 1665 to 1800, apparatus illustrations increased in number and detail as part of the article's increasing importance as a surrogate for first-person observation. Here, however, the verisimilitude of surrogate experience decreases as a significant rhetorical issue, to be replaced by the relation of the reported events to a more general theory. Authors seem less concerned to establish that the events occurred as reported than to show how these events fit with and elaborate the communally shared account of theory. When the community shares a generalized vision of the world, explicit connections to the abstractions carry more sense of veracity and more communally significant information than concrete representations of one-time events in the laboratory. Strong theories apparently can create stability of reliably reproducible events (see chapter 11) with greater force and generality than can concretely reported events, for the generality allows application to a variety of circumstances, while the concrete event only encourages attempts at exact replication, with all the attendant difficulties. (See Collins, *Changing Order,* for a discussion of the difficulties of replication.)

ORGANIZATION, ARGUMENT, AND EPISTEMOLOGY

The features examined above strongly indicate the increasing abstraction, web of background information, density of knowledge, interpretation, and focused argumentation going into the *PR* article since 1893, but an examination of the structure of articles will reveal even more about the way discourse is intimately linked not only to knowledge and theory, but to epistemology—beliefs about what can be known, how it can be known, in what form it can be expressed and how it should be argued.

The analysis of organization and argument will examine three levels of data: (1) the self-identification of the article's structure as embodied in formal divisions and section headings; (2) the proportion of space devoted to the various parts of the argument; (3) the texts themselves, to extract the mode of argument and the logic of presentation.

Prior to 1950, only about half the articles had formal divisions with section titles; after 1950, section headings were a consistent feature of almost all articles. Moreover, section divisions became more complex after 1950; prior to 1950, those articles using subdivisions averaged 4.5 per article, while in 1950 and after, the average was 7.4. All articles in the decade-by-decade selection were examined for this feature.

Before 1930, those division headings that exist indicate that articles ended with results, with no conclusion or discussion sections, as though the results could stand alone and complete in their meaning. Before 1910, some articles contained conclusory sections, but only in the form of summaries of results. Starting in 1930, however, discussion and conclusion sections—sometimes so labelled, sometimes given more substantive titles—became increasingly common. This again is a clear indication that the articles have become issue-oriented rather than fact-presenting.

Similarly, with a single exception (1901-BEM, which later content analysis will show not to be anomalous), articles did not have explicit theory sections, although they appear with some frequency since then.

Early articles, then, basically have methods and results sections, sometimes with two or three methodological sections. More recent articles tend to have only one methodological section, but several discussion, conclusion, and theory sections. Moreover, in early articles those sections given original names tended to be methodological; for example, in 1910-EIN/EM, the first four of the five sections are methodological and are given specific descriptive names: "Determination of the Distribution of Energy in the Spectrum of the Comparison Flame," "Comparison of the Fluorescence Spectra with the Spectrum of the Standard Acetylene Flame," "The Correction for Slit-width," and "The Correction for Absorption." More recent articles, on the other hand, give methodological sections standard names (for example, "Experimental") and give original names to discussion and interpretation of results on occasion, as in 1980-RAR et al.:

I. Introduction
II. Experimental
III. Results
IV. Interpretation—A. *Yb* ($5p^6 4f^{14} 6s^2$)—1. Autoionization, 2. Auger Decay, B. *Ba*($5p^6 6s^2$)—1. Autoionization, 2. Auger Decay.
V. Discussion
VI. Conclusions
Acknowledgment

These titling choices indicate that early authors considered methodological sections to present special problems and achievements, while more recent authors are inclined to call attention, and give specific designation, to the theoretical meaning of the data.

Finally, acknowledgments sections did not explicitly emerge until 1940 and were not a regular feature until 1960. The implications of this will be discussed later.

Analysis of the percentage of each article devoted to each part of the argument confirms and supplements previous findings. In the 1890s, the introduction and review of the literature sections were substantial, although, as indicated in earlier discussion of references, unfocused. By 1900, these parts had become more compact. Since then, the introductory material has expanded both proportionally and even more in absolute terms (as the size of articles has increased). Moreover, in recent years the introduction has been sometimes supplemented by presentations of background theory. Methods and apparatus sections have been generally decreasing in their proportional share of each paper. Results sections have always remained important, but, as noted earlier, the data display has tended to shift from tables to graphs. Tables still in use in recent years have tended to present conclusions, such as the identification of quantum-level transitions with specific spectral lines. Discussion and conclusion sections have taken increasingly large parts of the articles, sometimes becoming so intertwined with the presentation of data that the results section takes on a discussion character. Finally, acknowledgments disappeared after the first few years, only to reemerge in a different form around 1920. The acknowledgments of the 1890s were personal testimonials to friends and mentors. 1895-EIN is filled with passing acknowledgments of the aid of the author's brother, such as this:

> . . . a method nearly the same as that described by E. F. Nichols in the first volume of this Review. Indeed in many of the measurements Mr Nichols did me great service, bringing to bear upon what was in many respects an operation of unusual delicacy the skill attained by long practice in similar research.

The acknowledgments that reappeared in the 1920s were more spare, sharing limited forms of credit and recognizing institutional dependencies. Even the acknowledgment of intellectual fellowship lost personal effusiveness. These trends have continued, as indicated by the two following examples, the first from 1920-GR, and the second from 1980-TFG et al.:

> The present investigation was suggested by Dr W. W. Coblentz who has shown continued interest in the problem. The apparatus was placed at my disposal and set up in the Randal Morgan Laboratory of Physics at the University of Pennsylvania. Suggestions have been made during the progress of the work by Dr Goodspeed and Dr Richards for which I wish to express my appreciation.

> We would like to acknowledge stimulating communications with R. Morgenstern in the course of this work. This work has been supported by the US Department of Energy, Office of Basic Energy Sciences.

An examination of the actual arguments presented in the spectroscopic articles gives a deeper insight into how the features already discussed are intertwined with significant intellectual and epistemological changes in the field. The remaining analysis consists of descriptive characterizations of selected articles, presented chronologically to suggest a rhetorical history of the field.

These descriptive characterizations reveal the substantive consequence of all the features examined through various indicators earlier in this paper. We see here presented the evolution of the kinds of argument that result from the mobilization of all the features examined. And we will see that the evolution of the argumentation has direct epistemological implications as the arguments become more theory-based and ultimately self-conscious about their constructed theoretical character. For instance, 1893-EFN employs a rhetoric based on an empiricist epistemology. Spectral lines and the substances that produce characteristic patterns are taken as unproblematic objects of nature. The main task of the article is to present measurements of these unproblematic objects. References to earlier work are only general because they only need suggest that others have identified and measured similar phenomena. The main problems are of methodological technique and are discussed in some detail. Results are presented in graphs and tables; the accompanying text only repeats the information presented graphically with no further interpretation, only further methodological comments. The conclusion consists only of a summary of results—that is, a third repetition of the findings.

1900-CJR shares the same empiricist stand, but presents its tasks, methods, and findings in closer relation to the work of others, thereby making the article more focused, concise, and aware of the concept of a "problem." The task described was to take a series of measurements already done, but with one change of circumstances to note the differences in results. The area of study is taken as a given, not requiring a roll-call of forebears; other work is referred to only as it bears directly on the current work. The apparatus is described as "about the same as that used by Foley," although a truncated description follows. Significantly, the author avoids discussing a methodological problem of possible distortion by referring to Foley's earlier treatment of the issue. In presenting results the author relies on prior literature by noting only those lines not reported in previous studies. Not only does this selective reporting of findings lend conciseness, it focuses attention on these new readings appearing under changed conditions, making the readings "problematic," something to be accounted for. The accounting is done in two ways: first, by associating them with an earlier set of predictions and, second, by attributing some lines to a specific element. In a final section the author discusses the conflicting observations of two previous workers and then describes some new observations "of some interest in this connection." He does not, however, draw the problem more sharply or propose a resolution; he only adds new observations. Thus, conflicts in the literature and comparisons of his own findings to other findings in the literature suggest topics for discussion, but the discussion remains concrete, only rising above the level of observation and measurement.

1901-BEM, anomalous by several of the previous measures (number of references, lines of equations, and presence of a theory section) is explicable when examined from the perspective of argument and epistemology. The article is nevertheless unusual for it attempts to move beyond empiricism to create a link between theoretical discussion and experiment, although the link is awkward and not very intimate. If 1900-CJR is a slight machine that rises a bit above ground by no great will of its own, 1901-BEM is a massive piece of equipment that struggles mightily but gets no higher than the other. 1901-BEM opens with a general theoretical discussion, beginning with a first principle and synthesizing much existing theory in textbook fashion, but without any indication of where the theory is heading, what problem is being addressed or what issues are at stake in the experiment. If not for the title and outline standing at the head of the article, the first five pages would give little clue that this was an experimental paper. The author does eventually apply the theory to the particulars of the experiment, but never defines a specific issue at stake. The theory serves only as a description of the experimental conditions. The presentations of apparatus, method, and results are not distinguished in any way from those of simple empirical work. Most significantly, the data presented are not selective concerning an issue at hand, but rather seem presented for their own sake. The discussion of results consists mostly of how method might have been improved. A few low-level generalizations are made in passing, and a conflict in the literature is discussed, but the data at hand are not adequate for a conclusive resolution. The conclusions section consists of a numbered list summarizing a miscellaneous collection of earlier observations, some of which are methodological.

Moving forward, 1910-HEI uses references to prior work to establish a problem, discusses relevant theory, proposes a solution, then discusses the limitations of the solution. In many respects, from the embedding of the problem in the literature and theory to the focus on problem solution and the recognition of the constructed and limited nature of the solution, this article foreshadows the intellectual structure, argument pattern, and epistemological stance of later work, except that in this case the problem is methodological and the solution is a new piece of apparatus, rather than the problem and solution being in theory. This parallel suggests the analogy between physical apparatus and intellectual apparatus. A piece of machinery (in this case, a photospectrometer) is clearly a human invention; if there are faults or limits to the apparatus, a study of existing machines and an understanding of their theory can lead to diagnosis of the problem and construction of an improved machine addressing the difficulty. Moreover, since the new machine is also a human construction, it can be assumed to have new limitations. It is not so easy to see symbolic representations of nature—intellectual constructions—in the same light; such perception is likely to come only after a science becomes organized around theory rather than around "empirical facts," and then gains some sophistication about that theory. Over the next period we will find theory moving to the center of arguments and an increasing awareness of the constructed nature of theory.

By 1920, a few articles present more substantial integration of theory into the argument. 1920-CDC/DC, although largely empiricist in manner, begins with a purpose of theoretical consequence:

> A knowledge of the relation between the spectrum of a substance and that of its isotope is important in that it may throw further light on the structure of the atom.

Although the consequences of the finding of this study are never explicitly discussed in terms of theory of the atom, the experimental design and results reported are directly relevant to this theoretical task. In this case, even though theory has not changed the structure of the argument, it has helped select and focus the contents.

1920-WD/RAP adopts a theory-driven task more fully. The opening paragraph, entitled "Object," identifies specific measurements important "for the purpose of testing certain relations deduced from theories of the structure of atoms and the mechanism of radiation." Theory testing becomes here an element of argumentative structure; after presenting apparatus, methods, and results, the article discusses how the data correspond to several current theories and to calculations from equations, although only in a general way. Some theories are supported, others questioned, and limited conclusions drawn based on theoretical interpretations of the data (for example, "It would seem in this case the electrons producing the lines did not come from exactly the same outer orbit").

In 1920, several purely theoretical articles relevant to spectroscopy also appeared, whereas none had appeared in 1893–95, 1900–1901, or 1910. Kemble readjusts an earlier theory of his to make it consistent with Bohr's theory of the atom; Baly tries to correct an earlier paper by adjusting its conclusions to new theories and findings; and Webster compares theories and results of quantum phenomena in the X-ray and visible light regions to draw conclusions about emitting mechanisms and to find some limitations to Bohr's theory.[14] This array of articles indicates that by 1920 Bohr's theory has cast the field into a more theoretical vein.

14. Edwin C. Kemble, "The Bohr Theory and the Approximate Harmonics in the Infra-Red Spectra of Diatomic Gases," 2:15:2, 95–109; E. C. C. Baly, "Light Absorption and Fluorescence," 2:15:1, 1-7; and David L. Webster, "Quantum Emission Phenomena in Radiation," 2:16:1, 31–40.

Not only does the empirical work gain more of a theoretical basis, but theory itself is unsettled, requiring testing, evaluating, readjusting, reconciling, and, in some cases, abandoning. The new situation calls forth new kinds of arguments in both experimental and theoretical papers.

By 1930, quantum mechanics had stabilized sufficiently to provide the grounds for empirical work without the theory itself being in question. 1930-SS takes on a task located and identified by theory, a task that appears from the discussion of references to be already commonplace: elucidation of the terms of the spectrum for selected elements. That is, measured spectral lines are being associated with specific electron transitions within the structure and fine structure of the atom. Thus, although the experimental description follows the typical empirical pattern, the topic of discussion in the results section is the classification of results to determine term values and to associate lines with transition intervals. These classifications and associations, rather than the raw measurements, are represented in the results tables. Thus, results are processed intellectually within concepts and operations derived from theory, and are expressed in a language also derived from theory. With the ground theory established, specific questions of elaboration and identification of mechanisms in specific circumstances can then become recognized questions in the literature. That is, theory helps organize the literature.

1930-SB takes a further step into theory by finding its problem in the literature ("there has been a great deal of speculation concerning the identity of the emitter") and presents an experiment testing one hypothesis. Since the ground theory has helped identify the problem, others can also be working on the same problem; therefore, the author must discuss the work of a colleague who published while his own work was still in progress. The article elaborates theory extensively, using the tools of quantum mechanics and discussing how the analysis varies from others proposed, as well as how it relates to experimental results in the literature. The author is well aware that he has organized his work around the concept of a problem, for he explicitly states in the acknowledgments, "Dr R. S.Milliken suggested this problem. . . ."

In 1930-SKA/JHW, awareness of the constructed nature of theory and language allows the authors to suggest a nomenclature innovation to allow better identification and analysis of a particular phenomenon. The distance between symbol and object becomes a resource of investigation. Thus, in addition to the usual features of a theory-located, problem-based article, this article devotes much space to explaining and justifying the proposed nomenclature convention. The results and discussion sections, moreover, become cases of the application of the new nomenclature.

Articles in 1940 and 1950 continue in the style of the theory-located, problem-based article, with the problem sometimes coming from the split between theory and data (for example, 1940-SM) and sometimes from disagreements in the literature (for example, 1950-RBH et al.). In 1950-WFH/TL a new style of argument appears that will be more fully developed in 1960-HA/AH: the modelling approach. Epistemologically, the modelling approach sees a split between nature and theory, theory being only a human construction, having no reasonable expectation of giving a complete and accurate account of nature. Under such an approach, a paper cannot propose a theory test, proving the truth or falsity of a claim, but can only propose a model that accounts for the data better than other available models. In terms of argumentative structure, a modelling article does not present a claim in the beginning to be explained, supported, and discussed in light of experimental data; instead, once the article locates the problem in relevant theory and presents appropriate data, only then does it offer its model or claim about what apparently occurred in the experiment. Results are first presented, then puzzled over. Only after the puzzlement is the provisionally best model presented.

Once the argument moves away from notions of absolute truth and error, the concept of fit between theory and data becomes more important. Consequently, 1970-NWJ/JPC finds its problem in the deteriorating quality of fit between one category of data and a new theory gaining acceptance because it improves fit with respect to other categories of data. The experiment is designed to find the cause of the discrepancy. The article ends by calling for new theory and experimental work.

1980-KF et al. compares the fit between two sets of experiments and two models. As knowledge has grown, theory elaborated, work proliferated, and individual problems have become located more and more specifically within the web of prior work, articles have become increasingly tentative about the certainty and epistemological status of their claims.

Discussion

What information people in a group convey to each other, the purposes for which they present that information, their means of persuading each other of the validity of their statements, the uses others make of the statements, and the features of discourse they develop to realize these activities are all important aspects of a group's communal life, especially when a major activity of that group is to produce statements. The apparent function of the community of research physicists is to produce statements to be validated by that community as knowledge. The character of the statements presented for communal judgment embodies major (although not all) aspects of the community's social relations, and changes in the character of those statements represent changes in the social relations and social structure. Further, if, as in the case of *PR*, the changes in character of the statements are intertwined with cognitive changes of a discipline, discourse provides a concrete mechanism by which social behavior, social action, and social structure are related to cognitive structure.

Specifically, the discourse style in *PR* at the time of its founding suggests a group tied together by traditions of work, common objects of interest, common techniques, and personal apprenticeship loyalties. Its members engaged in a loosely organized mapping activity, confident of the solidity of the ground they were mapping, of the appropriateness of the tools and of a simple correlation between the ground and the map. Each contribution had only to identify the piece of ground, describe the tools, and present a piece of the map, with no particular need to demonstrate coherence within the piece or among the pieces. Much of the contribution of each article was methodological, so apparatus and methods were described at length, both to allay criticism and to make the innovations available for others. This situation, as noted earlier, may reflect more on the state of American physics at the time than on the general condition of international physics.

In the early part of this century, the spectroscopic community in America became more organized around its shared work. Members would scrutinize each other's work for patterns and would harness the work of others into the arguments of their own new work. They showed increasing effort to establish generalizations and coherence among the shared work and started to organize their work around theories, often casting empirical work in the form of theory-testing. They also felt obliged to argue for the theoretical significance of their work in order to anticipate the newly emerging criterion of significance.

Bohr's theory of atomic structure offered a single ground theory upon which spectroscopy could organize itself and its work. At first the full meaning, range of validity, and manner of application of the theory were in question. Physicists argued basic theory with each other: experimenting, deriving calculations from theories, comparing theories and data, examining the fuller implications of theories. Rather than being torn apart into mutually exclusive camps, the physicists seemed to be drawn more closely together as they had to examine, compare, rely on, discuss each other's work more closely in order to establish theoretical generalizations that would ultimately be validated by the entire discipline.

As quantum mechanics became established, it provided a coherent organizing principle for work and argument, but in each new contribution the publishing spectroscopist had to attend to the relationship between his own work and the general theory by locating his work in the theory, elaborating aspects of the theory, showing the theoretical meaning of results, and discussing theoretical consequences. The increasingly elaborated theory became a means by which his own work became tied to others' work, to which he more often referred. Problems, localized and suggested by theory, became shared. Theoretical significance, correctness, and consistency became major criteria. Attending to these criteria and tasks increased both article length and density of expression. In order to make a well-formulated statement to one's colleagues, one had to communicate more information.

As theory grew, it became apparent that it was a construction, separate from the nature it described. This awareness affected argument and social relations. Hard answers were not to be expected. The tentativeness of the "modelling" or "fit" type of arguments mitigated the confrontational conflict of theoretical dispute by recognizing that each contribution was only part of a process.

Concluding Thoughts

The evolution of the spectroscopic article over the past century in America reflects the growing knowledge and theoretical character of science and reveals some of the institutional consequences of these changes. The large-scale trends revealed here are consistent with the traditional view that science is a rational, cumulative, corporate enterprise, but point out that this enterprise is realized only through linguistic, rhetorical, and social choices, all with epistemological consequences.

This particular study highlights how a strong theory not only shapes the scientific activity, but becomes an important means of ordering social relations. A widely shared and elaborated theory can provide discrete and robust venues for individuals where they may formulate their own interests and carry forth their own work. In this sense a theory may allow a kind of bureaucratization of the scientific community, allowing individuals to sort themselves out into distinctive research roles according to rational principles generated by the theory.[15]

This, of course, differs from the classical bureaucracy where roles and tasks are established from the top down, although such bureaucracies may well exist within certain laboratories. Here, rather, roles and tasks are negotiated between individuals bidding to work on, modify, develop, elaborate, or apply part of the theory and employers, funders, editors, referees, critics, and audiences who grant the researcher various powers to continue, publicize, and gain acceptance for their work (see, for example, Myers "Social Construction" and "Texts").

This change from scientific entrepreneurship, where each individual stakes a private claim that recognizes few overt and lasting connections to the claims of others, where each claim is under threat from each other claim, to scientific bureaucracy, where competition is rather to attach yourself firmly to a powerful part of the communal apparatus, raises many new and intriguing possibilities for communal and individual pathologies, resulting in widening divisions between the abstractions of the theory and responsible empirical experience. Yet by organizing the experience of large numbers of individuals, pointing the individuals toward new kinds of experiences, providing means for comparing and coordinating varied results, and establishing topics and procedures for discussion, a strong theory can ground its generalizations on the empirical experience of an entire community. Whether the research program and the attendant social community pursuing that program thrive depends in part on whether that research program generates interesting venues for research—that is, places where the program can attach itself to accounts of empirical experiences. Furthermore, the program can continue to thrive only if the accounts created by empirical research coordinate well with the more general account offered by the theory. Otherwise, following Lakatos' analysis, the research program degenerates, offering little satisfaction for the interests of individual scientists. Few will fight for seats on a train going nowhere.

Spectroscopic Articles from *Physical Review* Discussed in This Chapter

1893-EFN. Ernest F. Nichols. "The Transmission Spectra of Certain Substances in the Infra-red." Series I, volume I, number 1, pp. 1–18 [hereafter I:I:1, 1–18].

15. These thoughts owe obvious debt to Max Weber's discussion of bureaucracy in *The Theory of Social and Economic Organization.*

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