● *ABSTRACT*

Recent studies of scientific texts need to be set against the history of the genre, which in part establishes the institutional framework within which any individual text is created. The definition of the appropriate form of communication is part of how a discipline constitutes itself, and is part of the achievement of that discipline. This paper examines the changing features of spectroscopic articles in Physical Review *since its founding. Analyses of article length, use of references, sentence length and syntax, vocabulary, graphic features, organization and argument indicate that articles become increasingly theory-based and knowledge-embedded through time. Self-consciousness about the theoretical character of argument also increases. The changing character of communication within a scientific community also has implications for the social structure of that community.*

Modern Evolution of the Experimental Report in Physics: Spectroscopic Articles in *Physical Review*, 1893-1980

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Although historians of science have described the invention and rise of scientific journals,[1] the role of sponsoring institutions ,[2] and the influence of early editors,[3] and although sociologists of science have investigated the systems of communication and organized scepticism in which journals play significant roles,[4] our knowledge of the prose that appears in such journals remains mostly limited to normative characterizations derived from strictures proposed in the seventeenth century by Bacon, Sprat and Wilkins.[5] Such commonplaces as:
1. the scientist must remove himself from reports of his own work and thus avoid all use of the first person;
2. scientific writing should be objective and precise, with mathematics as its model;
3. scientific writing should shun metaphor and other flights of rhetorical fancy to seek a univocal relationship between word and object; and

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4. the scientific article should support its claims with empirical evidence from nature, preferably experimental;

stand not only as advice to erstwhile scientists, but as actual descriptions of what scientific writing has been and currently is. Even if such characterizations were descriptively true, they do not provide an adequately rich account of the characteristics of the genre or the features of the prose, nor do they provide an historical account of the development of such writing.[6]

Recent sociological and linguistic studies of scientific texts have begun to illustrate the complexity of scientific writing and the character of some of its features. The now substantial body of sociological studies examining the construction of single texts or closely related groups of texts, has established that authors control the language and presentation of their papers so as to present their work in the most persuasive or favourable light, so as to advance the acceptance of their own work and to further their interests as scientists.[7] Most aspects of the article, at times even the presentation of data, are open to forms of literary control, but writers seem to be particularly concerned that their work is presented in a form that will meet the criteria of judgment likely to be imposed by the readers, and that will show the importance of the work, in relation both to prior literature and to possible future work. A few studies have also been concerned with the possible constraints and accountabilities that limit such textual manipulation.[8] The overall conclusion to be drawn from all these studies is that scientific writers indeed write their texts to serve their own scientific interests.

Linguistic studies of scientific syntax have worked with contemporary summary genres — that is, textbooks and abstracts, removed from the struggle of scientific persuasion.[9] These studies have, accordingly, tended to find that scientific writing is formulaic and impersonal, apparently concerned with a representation of nature rather than with the advance of a claim and a career.

Each of these approaches, although revealing much, reveals only part of the story. Each, nevertheless, tends to interpret its part as the whole. The linguistic studies portray scientific research as a rational empirical stable enterprise, with neither a personal nor an historical dimension. Most of the sociological studies, because they are concerned with individual choice, treat each article as though it were written in a free play of persuasive imagination, although there may be an occasional recognition, as by Law and Williams,[10] of stylistic and grammatical acceptability which implies conventions that precede any particular article and helps define what constitutes an acceptable scientific paper.

In most of the sociological studies, the previous literature, as a validating set of scriptures, is a resource to be drawn from and effectively arrayed through references, but its role in defining the current work is not considered.[11] The sociological study of scientific texts, in an attempt to free itself of positivist historical whiggishness, which finds in scientific papers the inevitable march towards 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 social-historical context.[12] 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 time periods and across all disciplines — from early nineteenth-century geology, contemporary applied protein synthesis, biochemistry, physics and parapsychology — are all treated equivalently as sources for generalizations.

The continuity (and consequent current peculiar situation of a discipline — or, more particularly, the writing within a discipline) may be contained not solely within the substantive problems and knowledge of a discipline (as has been the concern of both historians and philosophers of science), but also within the institutional arrangements. With respect to writing, the constraints and opportunities provided by the accepted genre and style at any particular time and in any particular discipline, may be a significant set of institutional factors.[13] That is to say, the individual writer, in making decisions concerning persuasion, must write within a form that takes into account the audience's current expectation of what appropriate writing in the field is. These expectations provide resources as well as constraints, for they provide a guide as to how an argument should be formulated, and may suggest ways of presenting material that might not have occurred to the free play of imagination. Moreover, the conventions of genre and style help designate issues for particular attention and persuasion. The conventions provide both the symbolic tools to be used and suggestions for their use.

Although conventions help define the possibilities of a piece of writing, they do not absolutely constrain; for conventions change, and the change occurs particularly through the nonconforming choices made by a series of writers that then become the new norm. The forces and motives behind these changes may be various, ranging from changing social conditions to changing intellectual conditions, from self-interest to reason.[14] The conventions of writing in a discipline are as much a product of the discipline as are its knowledge claims. Moreover, since the institutional arrangements of writing conventions directly affect the symbolic representations that constitute knowledge, writing conventions help define the very thing called 'knowledge'.

This essay, in characterizing the changing features of an historically developing body of scientific articles within one discipline, will suggest how the conventions of prose features are part of the historical accomplishment of a discipline, closely related to its changing intellectual and social structure. How a discipline decides to communicate with itself, what it presents as potential contributions to knowledge, and how it conceives and argues for those potential contributions, are essential parts of how a discipline constitutes itself in fulfilment of its task of creating knowledge. In particular, this paper will examine the changing features of articles appearing in the *Physical Review* (*PR*) from its founding in 1893 until 1980.[15] This period marks the rise of American physics from backwardness to world dominance,[16] reflected by the journal's rise from a local, university organ to the primary international journal of physics.

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;[17] this growth can also be seen in the increase of equivalent words appearing annually in *PR*.[18]

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, but only (at least at this stage of methodological development) about the most surface features of a text. 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 endeavour 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 I 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.

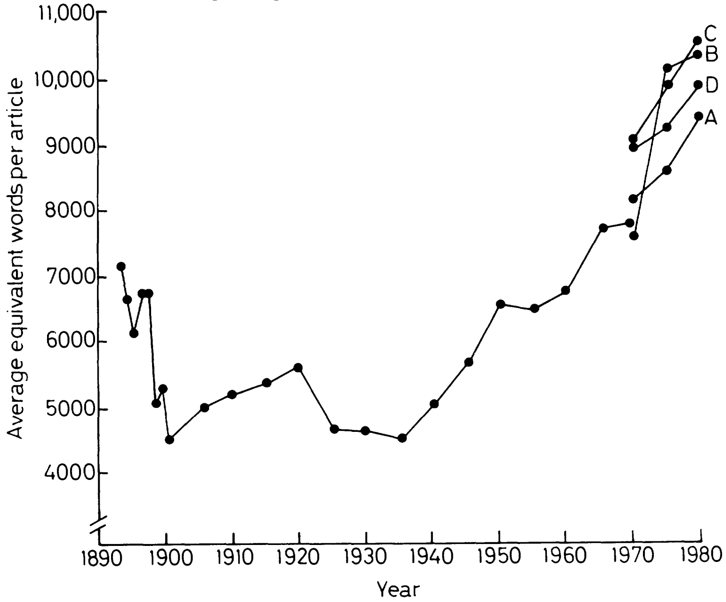
The limitation of material does, unfortunately, leave open several questions about the generality of the findings. First, the narrowing to experimental articles eliminates consideration of developments in the purely theoretical article, of increasing significance in recent decades. Second, without a 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 styles. 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 1). From 1893 until 1900, the average length of

FIGURE 1
Average Length of Article in *Physical Review*



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.[19]

Figure 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 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.

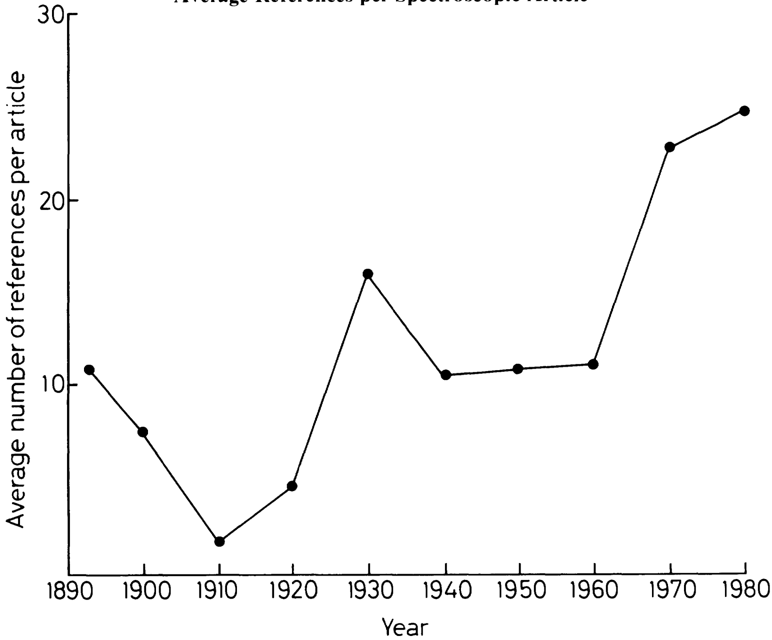
Similarly, changes of editor seem to have had, at most, a marginal effect on article length. Turnovers of the editorship occurred in 1913, 1923, 1926, 1950, 1951 and 1975. The 1913 and 1975 turnovers do not correspond to any changes in the graph; the turnovers in the mid-1920s and early 1950s do correspond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

The data to be analyzed in the remainder of this paper 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, re-evaluating 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

FIGURE 2
Average References per Spectroscopic Article



changed significantly in the articles examined, suggesting the increasing embedding of arguments in the web of the literature of the field. Figure 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.[20] 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 dispersion 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; he continues:

> 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 1900-01, 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.[21] 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 ¼ ω_{pe} and ½ ω_{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 ½ $n\omega_{pe}$ with $1 \leqslant n \leqslant 8$; $n \neq 7$ for $H\alpha$. The predicted positions are marked in Fig. A. Because of the 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 co-ordination. 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.[22] 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, 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.[23]

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).[24] 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.

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 to 79 percent of main clause nouns 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 centred 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 increase 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 fibre, 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 I, Volume I, 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.[25]

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 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 neighbouring 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, multi-part 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, of course, a clear indicator of the integration of theoretical explanation and prediction into the argument of the paper.

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-identificaton 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
Acknowledgement

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, acknowledgements 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 conforms 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, acknowledgements disappeared after the first few years, only to re-emerge in a different form around 1920. The acknowledgements of the 1890s were personal testimonials to friends and mentors. 1895-EIN is filled with passing acknowledgements 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 acknowledgements that re-emerged in the 1920s were more spare, sharing limited forms of credit and recognizing institutional dependencies. Even the acknowledgement 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 slightly 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 interesting, 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 centre 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, 1900-01, 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.[26] This array of articles indicates that by 1920 Bohr's theory has cast the field into a more theoretical vein. 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 acknowledgements, '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 embody 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 behaviour, 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.

Conclusions

The evolution of the spectroscopic article over the past ninety years 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 means and choices, all with epistemological consequences. Moreover, the approach presented here tends to wash out the contexts of individual articles, and therefore the local choices of potentially indexical and interested character.

Knowledge of the history of genre and style is not the full story of functioning discourse; it only provides an account of the prior products of communication processes, stripped of the vivifying circumstances that gave the documents both intellectual and social meaning in their times. Nevertheless, this account is a necessary backdrop to any particular text, and any study of the nature and use of scientific texts would be wise to consider the linguistic tools available to any particular writer, and the implications of those tools. Even as the conventions constrain a writer, they may be mobilized and manipulated to the writer's advantage. In whatever form the conventions make their presence felt, they are the basis of many writing choices. And the development of those conventions themselves contains significant information about the history and character of the discipline which has seen fit to use them. As much as any of the other institutional arrangements of science, writing conventions are significant social facts for the communal operation of science.

• *APPENDIX*

Selection of Experimental Spectroscopy Articles from the *Physical Review*

1893-EFN Ernest F. Nichols, 'The Transmission Spectra of Certain Substances in the Infra-red', Series I, Volume I, Number 1, pages 1-18 [hereafter I:I:1, 1-18].

1895-EIN Edward I. Nichols, 'The Distribution of Energy in the Spectrum of the Glow-Lamp', I:II:4, 260-76.

1895-EM Ernest Merritt, 'On the Absorption of Certain Crystals in the Infra-red as Dependent on the Direction of the Plane of Polarization', I:II:6, 424-41.

1900-CJR Carl J. Rollefson, 'Spectra of Mixes', I:XI:2, 101-04.
1901-BEM B.E. Moore, 'A Spectrophotometric Study of the Hydrolysis of Dilute Ferric Chloride Solutions', I:XII:3, 151-76.
1910-EIN/EM E.I. Nichols and Ernest Merritt, 'Studies in Luminescence: XI. The Distribution of Energy in Fluorescence Spectra', I.XXX:3, 328-46.
1910-HEI Herbert E. Ives, 'Scattered Light in Spectrophotometry and a New Form of Spectrophotometer', I:XXX:4, 446-52.
1920-GR George Rosengarten, 'The Effect of Temperature upon the Transmission of Infra-red Radiation Through Various Glasses', II:XVI:3, 173-78.
1920-CDC/DC C.D. Cooksey and D. Cooksey, 'The High Frequency Spectra of Lead Isotopes', II:XVI:4, 327-36.
1920-WD/RAP William Duane and R.A. Patterson, 'On the X-ray Spectra of Tungsten', II:XVI:6, 526-39.
1930-SB Sydney Bloomenthal, 'Vibrational Quantum Analysis and Isotope Effect for the Lead Oxide Band Spectra', II:XXXV:1, 34-45.
1930-SKA/JHW Samuel K. Allison and John H. Williams, 'Experiments on the Reported Fine Structure and the Wave-length Separation of the Kß Doublet in the Molybdenum X-ray Spectrum', II:XXXV:2, 149-54.
1930-SS Stanley Smith, 'An Extension of the Spectrum of Thallium 11', II:XXXV:3, 235-39.
1940-SM S. Mrozowski, 'Hyperfine Structure of the Quadrupole Line 2815A and of Some Other Lines of Ionized Mercury', II:LVII:3, 207-11.
1950-WFH/TL W.F. Hornyak and T. Lauritsen, 'The Beta-Decay of B^{12} and Li^{8}', II:LXXVII:2, 160-64.
1950-RBH et al. R.B. Holt, John M. Richardson, B. Howland and B.T. McClure, 'Recombination Spectrum and Electron Density Measurements in Neon Afterglow', II:LXXVII:2, 239-41.
1960-HA/AH H. Arbell and A. Halperin, 'Thermoluminescence of ZnS Single Crystals', II:CXVII:1, 45-52.
1970-NWJ/JPC N.W. Jalufka and J.P. Craig, 'Stark Broadening of Singly Ionized Nitrogen Lines', IIIA:I:2, 221-25.
1980-RAR et al. R.A. Rosenberg, S.-T. Lee and D.A. Shirley, 'Observation of a Collective Excitation in the Ejected-Electron Spectra of Yb and Ba', IIIA:XXI:1, 132-39.
1980-TFG et al. T.F. Gallagher, K.A. Safinya and W.E. Cooke, 'Energy Analysis of the Electrons Ejected in the Autoionization of the Ba $(6p_j\ 20s_{1/2})_S$ States', IIIA:XXI:1, 148-50.
1980-KHF et al. K.H. Finken, R. Buchwald, G. Bertschinger and H.-J Kunze, 'Investigations of the Ha line in Dense Plasmas', IIIA:XXI:1, 200-06.
1980-KF et al. K. Friedriksson, H. Lundberg and S. Svanberg, 'Fine- and Hyperfine-Structure Investigation in the $5^2D - n^2F$ Series of Cesium', IIIA:XXI:1, 241-47.
1980-SJR Stanley J. Rosenthal, 'Differential Stark Effect in the Ground-State Hyperfine Structure of Gallium', IIIA:XXI:1, 248-52.

NOTES

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1. See, for example, D.A. Kronick, *A History of Scientific and Technical Periodicals: The Origins and Development of the Scientific and Technical Press, 1665-1790* (Metuchen, NJ: Scarecrow Press, 2nd edn, 1976) and A.J. Meadows (ed.), *Development of Science Publishing in Europe* (Amsterdam: Elsevier Science Publishers, 1980).

2. See, for example, Roger Hahn, *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666-1803* (Berkeley, Calif.: University of California Press, 1971); Margery Purver, *The Royal Society — Concept and Creation* (London: Routledge & Kegan Paul, 1967); and Dorothy Stimson, *Scientists and Amateurs: A History of the Royal Society* (New York: Henry Schuman, 1948).

3. Lotte Mulligan and Glenn Mulligan, 'Reconstructing Restoration Science: Styles of Leadership and Social Composition of the Early Royal Society', *Social Studies of Science*, Vol. 11 (1981), 327-64.

4. This would include work in citation studies as well as communication patterns — for example, C.E. Nelson and D.K. Pollock (eds), *Communication Among Scientists and Engineers* (Lexington, Mass.: D.C. Heath and Company, 1970) — and evaluation, growing out of the seminal article by Harriet Zuckerman and Robert K. Merton, 'Patterns of Evaluation in Science: Institutionalization, Structure and Functions of the Referee System', *Minerva*, Vol. 9 (1971), 66-100.

5. Francis Bacon, *Magna Instauratio* (London, 1620); Thomas Sprat, *History of the Royal Society* (London, 1667; London: Routledge & Kegan Paul, 1959); John Wilkins, *An Essay Towards a Real Character and a Philosophical Language* (London, 1668).

6. Although much recent evidence — starting with P.B. Medawar, 'Is the Scientific Paper Fraudulent?', *Saturday Review* (1 August 1964), 42-43, and including many of the articles referred to below — seriously calls the truth of such commonplaces into question, the intention here is not to evaluate the descriptive accuracy of these commonplaces. Nor is it the purpose here to evaluate discrepancies between classical accounts and modern strictures, nor to judge the historical effect of the classical reformist programmes. The intention is only to provide a richer, more historically sensitive description of scientific writing.

7. H.M. Collins and T.J. Pinch, *The Social Construction of Extraordinary Science* (London: Routledge & Kegan Paul, 1982); G. N. Gilbert, 'Referencing as Persuasion', *Social Studies of Science*, Vol. 7 (1977), 113-22; Gilbert and M. Mulkay, 'Contexts of Scientific Discourse: Social Accounting in Experimental Papers', and S. Woolgar, 'Discovery: Logic and Sequence in a Scientific Text', in K.D. Knorr, R. Krohn and R. Whitley (eds), *The Social Processes of Scientific Discovery* (Dordrecht, Holland: D. Reidel, 1981), 269-94, 239-68; J. Gusfield, 'The Literary Rhetoric of Science', *American Sociological Review*, Vol. 41 (1976), 16-34; K. Knorr-Cetina, *The*

Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science (Oxford: Pergamon, 1981); B. Latour, 'Essai de Science-Fabrication', *Etudes Francaises*, Vol. 19 (1983); Latour and P. Fabbri, 'La Rhetorique de la Science', *Actes de la Recherche*, Vol. 13 (1981), 81-95; Latour and Woolgar, *Laboratory Life* (Beverly Hills, Calif.: Sage, 1979); J. Law and R.J. Williams, 'Putting Facts Together: A Study of Scientific Persuasion', *Social Studies of Science*, Vol. 12 (1982), 535-58; J. O'Neill, 'Marxism and the Two Sciences', *Philosophy of the Social Sciences*, Vol. 11 (1981), 281-302; S. Yearley, 'Textual Persuasion: The Role of Scientific Accounting in the Construction of Scientific Arguments', *Philosophy of the Social Sciences*, Vol. 11 (1981), 409-35. These and other studies are discussed in C. Bazerman, 'Scientific Writing as a Social Act', in P. Anderson, J. Brockmann and C. Miller (eds), *New Essays in Technical Writing and Communication* (Farmingdale, NY: Baywood, 1983), 156-84; and in D. Edge, 'Is There Too Much Sociology of Science?, *Isis*, Vol. 74 (1983), 250-56.

8. C. Bazerman, 'The Writing of Scientific Non-Fiction: Contexts, Choices, and Constraints', *Pre/Text*, forthcoming; L. Fleck, *Genesis and Development of a Scientific Fact*, trans. F. Bradley and T. Trenn (Chicago: The University of Chicago Press, 1979); and G. Myers, 'The Uses and Limits of Rhetoric: Two Case Studies of the Composing Processes of Biologists' (paper delivered at the Society for Social Studies of Science, Blacksburg, Virginia, November 1983).

9. For example, M. Gopnik, *Linguistic Structures in Scientific Texts* (The Hague: Mouton, 1972); and K.C. Lee, *Syntax of Scientific English* (Singapore: National University of Singapore Press, 1978).

10. Law and Williams, op. cit. note 7, 552.

11. See Gilbert; Knorr-Cetina; Latour and Woolgar; and O'Neill; all op. cit. note 7.

12. Latour and Woolgar, op. cit. note 7, have placed rhetoric within the context of an agonistically structured field, but this still remains a local context.

13. Fleck, op. cit. note 8, through the concept of 'thought style', examines the constraints and implications of the conventions of expression throughout the history of anatomy and medicine. The definition of the conventions within which major authors wrote and upon which they innovated is, of course, a major project of literary scholarship. A standard problem of Shakespearean studies, for example, is the relationship between originality and conventions in Shakespeare's sonnets.

14. J. Agassi, *Faraday as a Natural Philosopher* (Chicago: The University of Chicago Press, 1971), Chapter 5, specifically argues that Faraday self-consciously reformed writing in physics.

15. Extensive background on the development of *Physical Review* appears in Zuckerman and Merton, op. cit. note 4, and The Physics Survey Committee, National Research Council, *Physics in Perspective IIB. The Interfaces* (Washington, DC: National Academy of Sciences, 1973), 1331-84.

16. Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (New York: Knopf, 1977).

17. Derek J. de Solla Price, *Little Science, Big Science* (New York: Columbia University Press, 1963).

18. 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 non-word 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.

19. Helmut A. Abt, 'Some Trends in American Astronomical Publications', *Publications of the Astronomical Society of the Pacific*, Vol. 93 (1981), 269-73; Physics Survey Committee, op. cit. note 15, 1367.

20. I have followed the procedure of examining references within the context of the entire article, as recommended by D. Chubin and S. Moitra, 'Content Analysis of References', *Social Studies of Science*, Vol. 5 (1975), 423-41. I use a fuller descriptive technique, rather than the kind of formal typology proposed by Chubin and Moitra or M. Moravcsik and P. Murugesan, 'Some Results on the Function and Quality of Citations', *Social Studies of Science*, Vol. 5 (1975), 86-92, 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', *Social Studies of Science*, Vol. 8 (1978), 327-40; and S. Cozzens, 'Life History of a Knowledge Claim' (paper presented at the Society for Social Studies of Science, Atlanta, Georgia, November 1981).

21. 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.

22. 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.

23. 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 simplication and shortening of the English sentence in America over this century.

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

25. The detailed representation of novel apparatus has of course 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.

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

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