Jointly published by Elsevier Science Ltd, Oxford
and Akadémiai Kiadó, Budapest

Scientometrics,
Vol. 46, No. 1 (1999) 73–86

DIFFERENCES IN KNOWLEDGE PRODUCTION BETWEEN DISCIPLINES BASED ON ANALYSIS OF PAPER STYLES AND CITATION PATTERNS

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(Received June 2, 1999)

To identify the differences in the knowledge production between disciplines, we analyzed the relation between the average paper length and impact factor of 100 journals from 5 disciplines. We found negative correlation between the average length and the impact factor in the natural sciences, but not in the social sciences. We also analyzed the structures of paper and the citation patterns. These analyses are expanded to the comparison between Mode 1 and Mode 2. All results showed the natural sciences articles could emphasize the differences from previous studies and be diffused effectively by the short standardized style of paper.

Introduction

As *Snow*[1] stated about "two cultures" in 1959, there are cultural differences between the natural sciences, the social sciences and the humanities, as well as among their disciplines. Each discipline usually has particular aims, objects and approaches that lead to differences in what is required to get a new claim accepted as validated knowledge by peers. Since the criteria for validating knowledge (called "validation boundary" by *Fujigaki*[2]) in each discipline are recognized implicitly among the researchers in that discipline, outsiders cannot know them explicitly. Therefore, cross-disciplinary conflicts occur due to differences between these validation boundaries, making collaboration between disciplines difficult.

However, since knowledge claims are submitted, referred, and diffused in the form of academic papers, the implicit criteria used for validation should affect the textual dimensions of papers; for example, it should be reflect in the length of paper, the relative length of each sections (introduction, method, data, results, discussion, conclusion, etc.) as well as in the number of equations, figures and tables.[3] The textual

0138–9130/99/US $ 15.00

styles by which words, sentences, and figures are aggregated into a paper are different between disciplines in the natural sciences, social sciences, and humanities, and between journals in each discipline.

In the present study, we looked for differences in the production of knowledge among the sciences in the styles of their papers. The styles of papers have been analyzed from various perspectives. *Bazerman*[4] examined the transition of styles with the cognitive development in one journal; *Sengupta*[5] and *Seglen*[6] estimated the information contents of one paper from its textual characteristics; *Snizek* et al.[7] examined the relation between various components of a paper and the citation rates; *Bourke* and *Butler*,[8] *Hemilin*,[9] and *Finkenstaedt*[10] analyzed publication types from the point of the evaluation. However, most of this work focused on one discipline or one journal and did not examine differences among disciplines. In the present study we focused on the differences in how knowledge is produced among the natural sciences, social sciences, and humanities.

We first analyzed the relation between the average paper length and impact factor of 100 journals from 5 disciplines to examine the following hypothesis. Since academic papers are required to state how the work being reported differs from previous studies (i.e., originality), the papers in each discipline should have a standardized style that is useful to emphasize the differences[2] (for example, standardized section-structure, which is usually recommended in the "instructions to authors" of many journals). By following a standardized style, papers should be shorter because only the necessary arguments are stated with little redundancy. Furthermore, high efficiency in diffusing new knowledge to peers by that style should increase the impact factor of a journal.

We next analyzed the average relative length of each section in papers in some journals, and the number of tables, figures, and equations to determine which arguments are given the most part of paper.

We then analyzed citation patterns to see if there were any differences in the way knowledge is accumulated and diffused. Since 1970, when *Price*[11] classified 154 journals of various disciplines by the number of references per paper and Price's Index (proportion of references that are to the last five years of literature), these indexes have been supported and used to identify "soft" and "hard" sciences (e.g., *Cozzens*,[12] *Moed*,[13] *Leydesdorff*[14]). In the present research, we identified the features of accumulation by analyzing the relation between such indicators and paper length and impact factor.

In addition to analyzing the differences between natural science, social science, and humanities, we analyzed the differences between Mode 1 knowledge production and that of Mode 2. The knowledge production of Mode 2 is characterized as the context of application, transdisciplinarity, and heterogeneity, which is contrastive to traditional Mode 1 activity (*Gibbons* et al.[15]). The differences between modes are considered to affect the styles of paper besides the differences among sciences. We should be able to observe these differences from the relative disciplines of Mode 1, by analyzing the styles of paper as a type of output.

Method and data

We selected five disciplines for analysis: physics and biochemistry as cases of the natural sciences, economics and sociology as cases of the social sciences, and psychology as a case of humanities. These disciplines are considered to typify the characteristics of their science and each has enough journals and academic papers to be analyzed. Along with these five disciplines, we looked at five·areas that have Mode 2 characteristics: materials science, biotechnology, management, communication theory, and artificial intelligence (AI). Drawing the boundary between Mode 1 and 2 is difficult since all these disciplines are considered to be located along a spectrum of modes. However, the five areas selected as Mode 2 are considered to have characteristics of Mode 2 than the first five disciplines we selected.

We first identified journals belonging to each discipline based on the categories given in the *Journal Citation Report* (science and social science editions) for 1996. We used journals as the unit of analysis since the disciplines can be identified by a set of journals and since the style of papers is different for each journal. The *JCR* for 1996 divided the disciplines into 181 categories in the natural sciences and 59 categories in the social sciences, and each journal is allocated one or more categories. We thus found categories corresponding to the ten selected disciplines.* The "psychology" were distributed between the *JCR* science and social science editions; we used the combined set. For each discipline, we selected the top ten journals in terms of their impact factor and ten other journals at random. We excluded journals with less than ten articles or reviews in one year, journals not included in the *SCI* or *SSCI*, journals consisting of mainly non-English papers, and journals that focus on a narrow area. For "artificial intelligence", we could find only 17 journals that met these requirements.

Using these selected journals, we measured the average number of pages per paper (only articles and reviews) in each journal. The average lengths was used to represent

* The *JCR* categories are "Physics", "Biochemistry & Molecular Biology", "Economics", "Sociology", and "Psychology" for Model and "Materials Science", "Biotechnology & Applied Microbiology", "Management", "Communication", and "Computer Science - Artificial Intelligence" for Mode 2.

the length of the arguments needed to produce a new knowledge claim in each discipline. The impact factors of the journals were analyzed to identify the differences in knowledge diffusion, re-use, and accumulation among the disciplines. We used the impact factor of each journal from the 1996 *JCR* and other data on the journals and papers from *SCI* and *SSCI* of 1994; the impact factor of 1996 shows the average number of times that articles published in a specific journal in 1994 and 1995 were cited in 1996.* The relations of these two values were analyzed in each disciplines to examine the hypothesis that the paper in standardized style with little redundancy should get many citation.

We also analyzed the average number of references per paper and the citing half-life** (and Price's Index) of journals published in 1994 to identify the characteristics of how knowledge is accumulated in each discipline. These average values were calculated excluding review journals (i.e., journals that included more review papers than article papers), and the average number of references in each journal was calculated using only articles (not review papers). These values were compared with the average page lengths and impact factors.

Results

Mode 1 field

The relation between the average number of pages per paper (the horizontal axis) and the impact factor (the vertical axis) in "physics" is shown in Fig. 1. Obviously, the "physics" journals can be divided into two groups. One group consists of a few journals with a high average number of pages and high impact factor; the other group consists of many journals with a few pages and a low impact factor. The three journals in the first group are considered as review journals. Review papers usually show the configuration of previous papers by citation in no limited pages (in this case, the average number of references in the review papers was 189, which is nine times as many as that in the article papers) and these configurations are used as basis for new research by others. In the latter group, there was a negative correlation between the average number of pages per article and the impact factor – i.e., journals with the highest impact factor had the

* For a strictly examination, we would have to use *SCI* and *SSCI* data from both 1994 and 1995. However the average number of pages per paper in a journal should not vary considerably over one year as long as each there are dozens of articles. Therefore, we used only 1994 data.

** Citing half-life means that the number of publication years from the current year that account for 50% of the current citations published by a journal in its article references.

smallest number of pages per article, and the more pages a journal article had, the lower its impact factor. The correlation coefficient excluding one journal (*Ann Phys-New York*, which was isolated from the article journal group, as seen in Fig. 1) was –0.556, which is significant at 5%. This value was not high, since the distribution of the average number of pages became wider as the impact factor decreased. Therefore, the dots, which indicate journals, form a leaning triangle in Fig. 1.

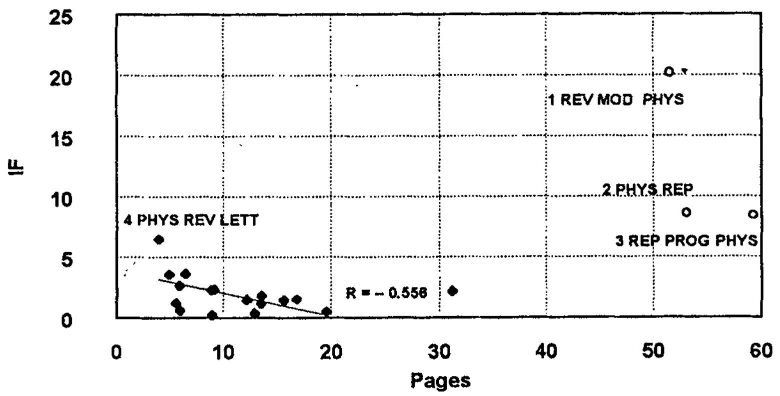

Fig. 1. Relation between the paper length and the impact factor of "Physics"

Using the number of pages to represent the length of paper is not rigorous since the size and format (margin, number of lines, etc.) of pages varies among journals. We therefore also used the number of words per paper. The number of words on one page of each journal was estimated by multiplying the number of lines per page* by the average number of words per line. The results using this approach were basically the same as those shown in Fig. 1.

The results for all five disciplines in Mode 1 are shown in Fig. 2. There are three clear patterns in the distribution. One pattern consists of "physics" and "psychology" (solid line), another is "biochemistry" (dotted line), and the other consists of "sociology" and "economics" (broken line). In each discipline of the first and second patterns, the journals fell into two groups (review journals and article journals). In the first pattern, "psychology" has similar distribution to "physics". Excluding the top three journals in terms of the impact factor (the review journals), the "psychology" article journals had a negative correlation between the number of pages and the impact factor

* The number of lines was counted for pages without any figures, tables, etc.

(the correlation coefficient of the article journals was –0.523, which is significant at 5%), and their dots formed a triangular shape in Fig. 2.

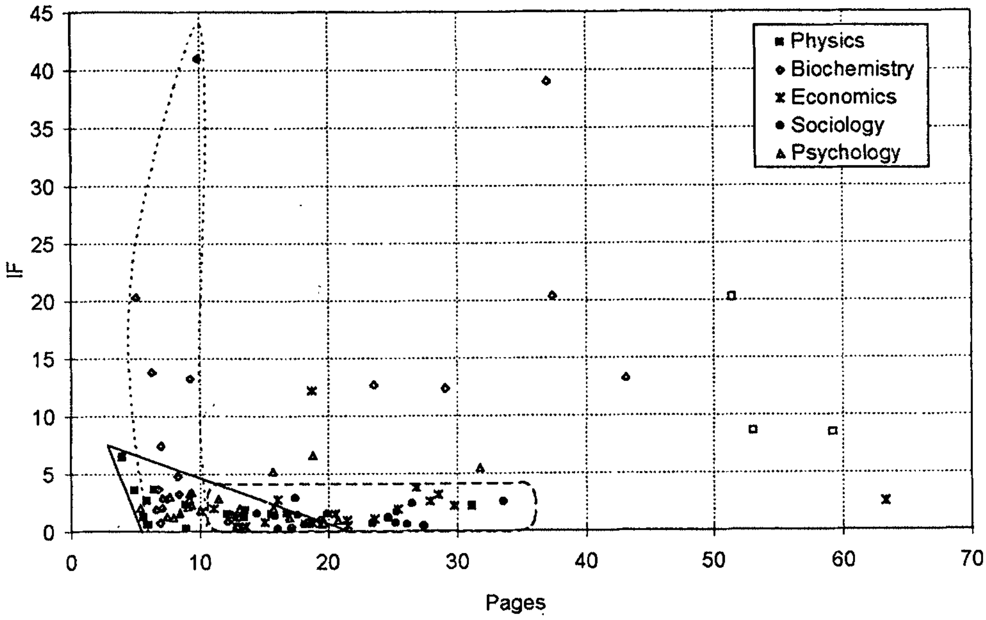

Fig. 2. Relation between the paper length and the impact factor of 5 disciplines in Mode 1

In "biochemistry", the average numbers of pages per paper in the article journals was between 5 and 10, excluding one journal, and the impact factors were much higher than for the other disciplines. We did not observe a significant correlation since again the distribution of the number of pages became wider as impact factor decreased. When we used the data for the top 20 article journals in terms of impact factor for "biochemistry" (excluding *Cell* since 20% of its papers were review papers), the correlation coefficient was –0.729 which is significant at 5%.

For the social sciences journals, we did not observe a significant relation between the length of papers and the impact factor. In both "economics" and "sociology", the average number of pages was large and varied, and the impact factor of most of the journals was very low. The review journals did not stand out and the journals with a high impact factor were not necessarily journals with short papers.

Table 1
Structure of sections

Physical Review A

(Atomic and molecular structure and dynamics)

		Text	References		Figures	Tables	Equations
1	Introduction	18%	22.2	44%	0.2	0.1	0.8
2	Method	30%	9.8	19%	1.6	0.5	1.1
3	Result	38%	14.9	29%	3.1	0.8	3.5
4	Discussion	14%	4.0	8%	0	0.3	0.5
	Total	100%	50.9	100%	4.9	1.7	5.9
			(uique 29.2)				

Cell

		Text	References		Figures	Tables	Equations
1	Introduction	13%	25.5	30%	0	0	0
2	Method	13%	24.3	29%	0.1	0	0
3	Result	47%	22.9	27%	7.6	0.5	0
4	Discussion	27%	12.0	14%	0.1	0.1	0
	Total	100%	84.7	100%	7.8	0.6	0
			(48.7)				

American Sociological Review

		Text	References		Figures	Tables	Equations
1	Introduction	36%	73.5	69%	0.2	0.1	0
2	Method	29%	15.6	15%	0.2	0.7	0.3
3	Result	20%	4.6	4%	1.7	2.1	0.2
4	Discussion	15%	12.5	12%	0	0	0
	Total	100%	106.2	100%	2.1	2.9	0.5
			(64.4)				

These different patterns raise the following question: Are these patterns caused by the structure of the papers (e.g., relative length of sections describing problem, procedure, results, etc.)? To answer this question, we looked at the relative sections lengths in *Physical Review A* ("physics"), *Cell* ("biochemistry") and *American Sociological Review* ("sociology"), whose papers represented three patterns. The average lengths were calculated from ten articles that used sections labeled "results" or "findings" and labeled "methods", "data", or "procedures" (i.e., paper reporting empirical studies).* We classified the sections into four categories: ("introduction", "methods", "results" and "discussion and conclusion").** Although the "results" section was longer in both *Cell* and *Physical Review A*, the latter had a longer "introduction" and "methods" section (Table 1). In *American Sociological Review*, the "introduction" was longer. These findings indicate articles in *Cell* require fewer arguments to set the agenda (i.e., the introduction section is shorter) than the other two journals, and the "results" sections in *Cell* article generally includes more figures.

Mode 2 field

The same analysis was performed using the five Mode 2 fields. As shown in Figs 3a–3e, the distribution patterns of the pages were almost the same between Mode 1 and Mode 2, and Mode 2 journals had a lower impact factor than the Mode 1. While significant correlation between the number of pages and the impact factor was not observed in the two natural science disciplines, there was a positive correlation in "management" ($r = 0.519$, significant at 5%) and in "communication theory" ($r = 0.640$, significant at 1%).

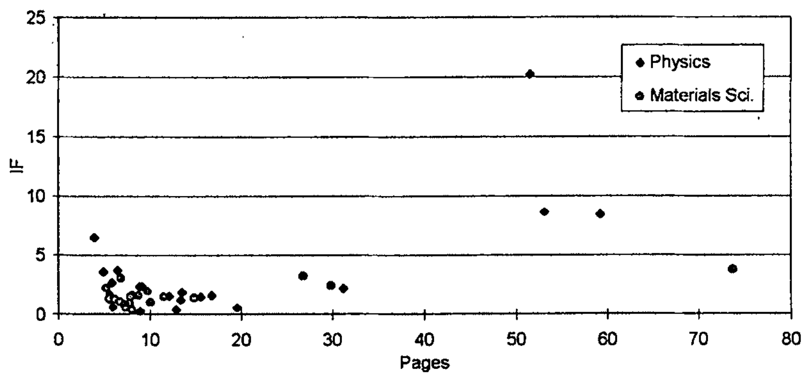

Fig. 3a. Comparison between Mode 1 and Mode 2 field (Physics and Materials Sci)

* We could not find any journal that had more than ten articles meeting this requirement in the journals for "economics" and "psychology" for 1994.

** "Introduction" included sections labeled "introduction", "background", and "previous research" and sections explaining the history and theoretical model that came before the empirical section. "Methods" included "methods", "data", and "experimental procedures". "Results" included "results" and "findings". "Discussion" included "discussion" and "conclusion". Sections labeled "results and discussion" were classified as "Results", but there were only 2 such papers.

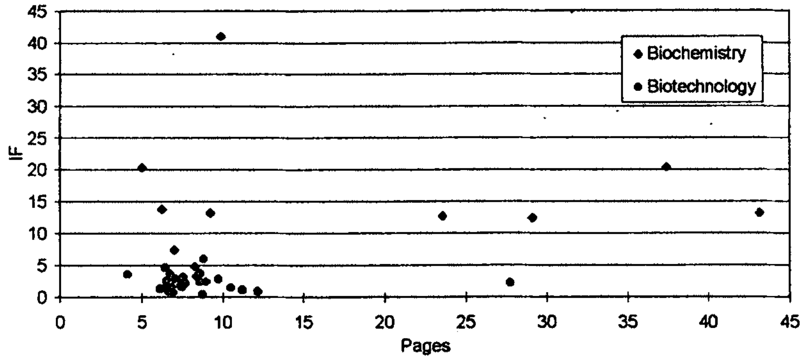

Fig. 3b. Comparison between Mode 1 and Mode 2 field (Biochemistry and Biotechnology)

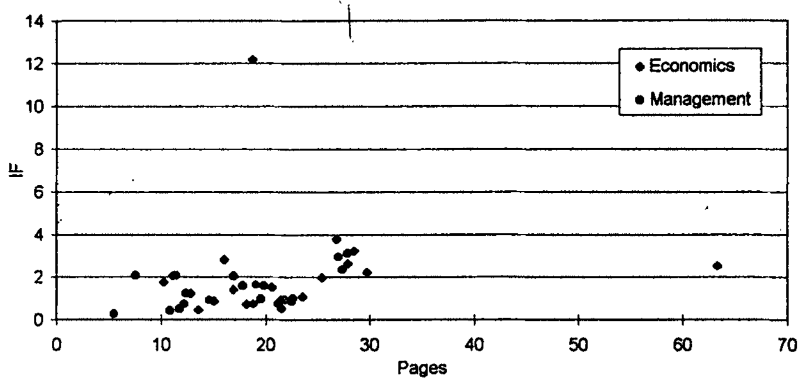

Fig. 3c. Comparison between Mode 1 and Mode 2 field (Economics and Management)

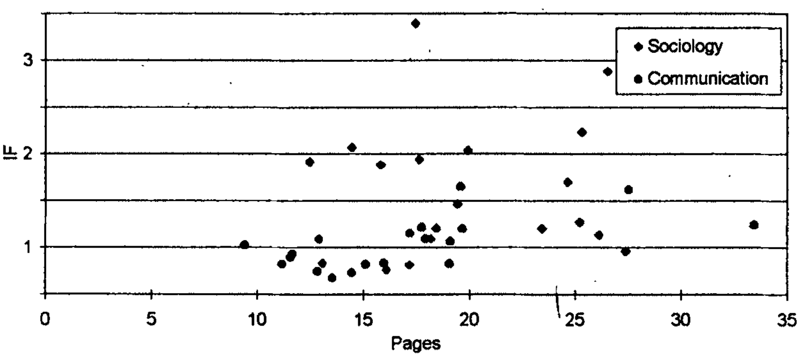

Fig. 3d. Comparison between Mode 1 and Mode 2 field (Sociology and Communication)

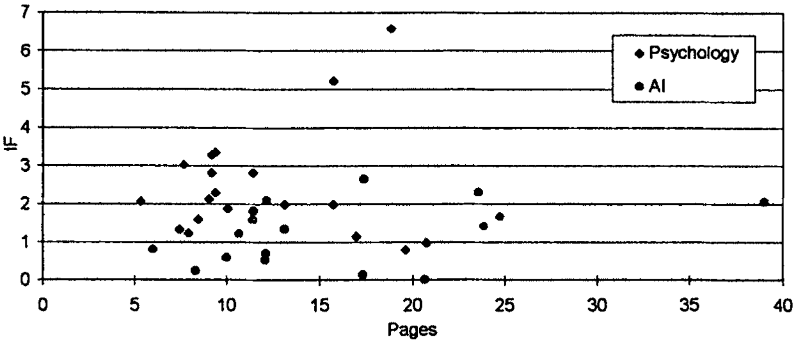

Fig. 3e. Comparison between Mode 1 and Mode 2 field (Psychology and AI)

Features of citation

In addition to analyzing the characteristics of knowledge production, we analyzed the features of citations to identify the characteristics of knowledge accumulation. The number of references (citing) in one paper and the rate of renewal of cited papers are important because they affect the increase of impact factor of a journal as well as reflect the features of the knowledge accumulation. Table 2 shows the average number of pages and references in each article (not including the review), the average citing half-life and Price's Index for 1994.* It shows that the average number of references in "biochemistry" articles was about the same as in social sciences and humanities articles. However, the number of references per page in "biochemistry" was more than in the other disciplines since papers in "biochemistry" have shorter pages. The Mode 2 journals had almost the same or fewer references per articles than Mode 1 journals, with the exception of "materials science" and "management". The "biochemistry", "biotechnology" and "AI" journals had the shortest citing half-life (Price's Index was large). The "biochemistry", "biotechnology" and "physics" journals had a significant negative correlation between citing half-life and the impact factor at the 1% level. This indicates that in these disciplines, the papers with high cited rates cite more recent papers.

* The average number of pages and citations were calculated from only articles (not reviews) using the *SCI* and *SSCI* for 1994. The citing half-life was calculated from only the journals that had more than ten articles (that is, not review journals) by using the *JCR* for 1994. When the citing half-life of a journal was "over 10 years" in the *JCR*, we used a value of ten.

Table 2
Citation patterns of disciplines

	Disciplines	Ave. No. of Pages (A)	Ave. No. of Ref. (B)	(B/A)	Citing Half-Life (C)	Price's Index	Correlation of (C) and IF
Mode 1	Physics	11.3	22.0	1.9	7.3	37.3	–0.71**
	Biochemistry	7.6	34.2	4.5	5.6	46.8	–0.72**
	Economics	21.9	28.6	1.3	7.0	35.8	–0.27
	Sociology	20.4	42.9	2.1	8.8	27.6	–0.25
	Psychology	11.0	34.9	3.2	8.2	30.2	–0.38
Mode 2	Materials Sci.	8.1	22.7	2.8	7.8	34.1	–0.44
	Biotechnology	7.9	27.0	3.4	6.3	41.2	–0.87**
	Management	17.1	40.3	2.4	7.8	31.6	–0.12
	Communication	17.1	34.5	2.0	7.8	34.2	0.12
	AI	16.0	24.4	1.5	6.0	41.4	0.26

(** significant at 1%)

Discussion

Our analysis of the relation between the paper length and the impact factor (Figs 1 and 2) showed two obvious groups of journals – review journals and article journals – in "physics", "biochemistry", and "psychology". In the article journal group, there was a negative correlation between the average number of pages and the impact factor. This suggests that short articles are more observed in the journals with a high impact factor. This tendency was not observed in the social sciences; The journals did not fall into two groups, the number of pages was large and varied, and the impact factors were less than in the natural sciences.

From these results, we conclude the following. First, in the natural sciences, the style of papers is firmly established and has a particular length. This is supported by the low distribution in the number of pages (particularly for "biochemistry" in Fig. 2). In contrast, in the social sciences, a style has not been established yet and the range in the number of pages is high. Second, knowledge production and diffusion are done very efficiently by the short articles in the natural sciences. The longer the articles, despite of the effort to write, the fewer citations they receive, so their efficiency is less. However, in the social sciences, there is no difference between short articles and long articles.

Psychology is often classified in the natural or social sciences besides in the humanities. The results for "psychology" were very similar to those for "physics" (Fig. 2), reflecting the fact that psychology today has some characteristics of the natural sciences. We can classify the five Mode 1 disciplines into three patterns based on our results: natural sciences including psychology, life sciences (biochemistry), and social sciences. However our citation analysis (Table 2) showed that "psychology" cite more old papers, as do social sciences ones, i.e., in terms of knowledge accumulation, psychology has characteristics resembling those of the social sciences.

From our structure analysis (Table 1), we observed that the "results" section is relatively long in short articles and has more figures in the natural sciences articles. In contrast, the "sociology" articles put more emphasis on the "introduction". In other words, research agendas and approaches are acceptable without long arguments in the natural sciences, indicating that the focus of research is clear among peers.

The results of the citation analysis also showed that there are more references in the short pages of the "biochemistry" articles (Table 2). This might indicate that long explanations to build the research agenda are made unnecessary by using many citations to show the differences from previous studies. Our finding that the articles citing recent papers are cited more frequently in the natural sciences indicates that differentiation from recent papers is more valuable in terms of citation, i.e., papers based on the recent layer of knowledge are preferred to reconstructing the whole network with past layers. These results imply that even though journals of various disciplines have the same number of references per paper or the same citing half-life (or Price's Index), they have different meanings between disciplines, so we cannot classify disciplines simply by these indices alone.

From these results we can sum up the features of the production and accumulation of knowledge as follows. In the natural sciences, the roles of review journals and article journals are distinguished explicitly. Therefore, articles are strongly required to state their originality i.e., "the differences from previous studies".[2] For this reason, articles tend to take a standardized style that focuses on the differences. In this style, the paper length is shorter and the "results" section, which can easily show the originality, is relatively longer. The "introduction" is made shorter by using more citations and fewer arguments. This style makes knowledge production and diffusion effective and speedy, and increases the rate of citation renewal.

In contrast, in the social sciences, papers do not take an established style as much as they do in the natural sciences. This may be due to the characteristics of objects, for example, a lack of re-occurrence, and the complexity and difficulty in making simple reduction for human society. These characteristics make possible to re-interpret past studies in other contexts that another author wants to discuss.[16,17] *Cozzens*[18] showed that in the social sciences, the same paper is often cited in various ways focusing on various points. Therefore, even when citing a paper, the author must make lengthy arguments to reconstructing past studies so as to support the author's insistence and to emphasize something-new in the results. The "introduction" is thus relatively longer in a social sciences paper, and consequently, the papers tend to be longer.

As for Mode 2, a significant negative correlation between paper length and impact factor was not observed in the "natural sciences", a significant positive correlation was found in social sciences ("management" and "communication"). This tendency, i.e., long papers are cited more in Mode 2 articles than in Mode 1 articles, indicates that papers with more information (even if a bit redundant) are valuable in not-rigidly structured area. However, the differences between Mode 1 and 2 varied among disciplines. "Materials Sciences" had shorter pages per paper with more references and a longer citing half-life than "physics", while "AI" had the opposite tendency in comparison with "psychology". It is apparently affected by the transdisciplinality and context of applications. "Materials Sciences" includes the characteristics of chemistry and physics, and "AI" also includes those of computer science which is developing rapidly. These mixed characteristics may be reflected in the values of each Mode 2 field. The common tendency among Mode 2 fields was a lower impact factor than in Mode 1. This may be due to several factors, such as the smaller number of researchers, the small number of references per paper, and the longer citing half-life.

Conclusion

We have analyzed the differences among the natural sciences, social sciences, and humanities based on the styles of their papers. Our analysis of the relation between paper length and impact factor, section-structure and citation pattern showed that there are different "cultures" in terms of knowledge production and diffusion, particularly in the differentiation of new knowledge claims from previous studies. For example, the natural sciences take a shorter, more standardized style in their papers, making knowledge production and diffusion more efficient, while the social sciences take various styles of paper. In the humanities, "psychology" reflected the cultures of both the natural and social sciences, so other disciplines must be analyzed in order to identify the characteristics of the humanities. Further studies are also required for the Mode 2 fields, including outputs other than academic papers.

A better understanding of these cultural differences should help to dissolve cross-disciplinary conflicts and provide a basis for using bibliometrics to evaluate different disciplines.[19] Future studies should look at how the characteristics of knowledge production and diffusion affect the cognitive dimensions.

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This research is partly funded by International Program in Special Coordinating Funds for Promoting S&T from Science and Technology Agency of Japan. The authors thank to the members of SOJIS (Self-Organization of the Japanese Information Society) project, J. *Makino* (Univ. Tokyo). M. *Shirabe* (Shinsyu Univ.), T. *Tomizawa*, K. *Watanabe* (NISTEP) and H. *Hirakawa* (ICU), as well as our European colleagues, L. *Leydesdorff* and P. Van den *Besselaar*, for their valuable comments.

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