Consensuality of Peer Nominations Among Scientists

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Science has been a remarkably efficient and productive human enterprise. Even if no more than 10% of scientific publications describe significant advances in knowledge and the majority are never cited even once (Rockefeller Foundation, 1978), those advances have done more to shape the world than most other events, natural or man-made.

What makes science so productive? One factor that sets science apart from other enterprises is the way in which its practitioners reach consensus about various claims to knowledge (Merton, 1973). Do they also reach consensus on the question of expertise—who among them is an important contributor and a good judge of contributions?

The lifetime citation count of a scientist's work measures his or her visibility. But the citing authors may praise or criticize his or her work,

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build on it or mention it in passing. Our study concerns peer judgments expressed directly in laudatory nominations. This provides information about the structure of science displayed in peer judgments, as distinct from simple visibility.

Strictly, consensus might imply that no objection could be found to designating the nominee as an expert. Our procedure does not take account of objections. Consensus about a scientist's eminence is measured by the number of peers who name him or her as one of the experts. In practice, the simple question of who comes readily to mind as an expert seem the most relevant question to ask to solicit peer judgments.

To enter the network linking scientists by ties of shared expertise and interest, we asked editors of key journals in each of six fields for their nominations. We then asked each of their nominees a similar question. After three rounds of nominations we began to analyze various aspects of our data. In one study we found that the distribution of nominations among scientists could be accounted for by the Yule-Greenwood distribution, a law of cumulative advantage (Kochen, Crickman, and Blaivas, 1982). In another study we examined the geographical correlates of nominations (Blaivas et al., 1981), and in another we examined the extent to which our sample of respondents was representative of the population (Crickman et al., 1982).

The present article reports another aspect of this study, incorporating data from all four rounds. We focus here on the individuals who received an exceptionally high number of nominations (above a threshold we have set, for convenience, at seven nominations). If the direction of science is internally governed by the weight of expert opinion, questions about the perception of expertise among scientists are relevant to the dynamics and even to the content of science.

Procedure

To initiate our study, we sent letters to 53 editors of key scientific journals asking them to name 10 experts in their fields from whom they would especially like to receive manuscripts and/or whom they would value as referees for manuscripts recently submitted. Our procedure resembles that used by Kadushin (1974) in his study of intellectual elites. The journals we selected represented six fields: (1) differential geometry, (2) low-dimensional topology; (3) information science; (4) human systems management, (5) general systems theory, and (6) future studies.

We chose these to include various contrasts: the first two are well-defined, established mathematical specialties, the rest are to various degrees newer or more diffuse fields. In the course of our study a seventh field, polymer chemistry, emerged unexpectedly when individuals named as experts in future studies identified themselves as polymer chemists instead. Thus our final sample included three hard sciences, three soft sciences, and one field on the borderline between science and nonscience.

Of the original 53, 40 responded, giving 415 nominations to 350 different experts. In the next round each of these 350 nominees was asked to name 10 experts in his field. We asked that the individuals named be "people whose work you try to keep up with, and whose competence, creativity, and judgment you respect." Of the 350 individuals asked, 104 responded, giving 1049 nominations to 771 different individuals. In the next round each of these 771 nominees was asked to nominate other experts in his or her field. However, the number of nominations was left to the discretion of the respondent in this case: the form provided had room for about 12 names. Of the 771 individuals asked, 156 responded giving 880 nominations to 701 different individuals. In the next round, the 440 of these nominees who had not been named and contacted in earlier rounds were asked for their own nominations, again with the number left to their discretion. Of these, 269 responded giving 2604 nominations. The total of 4948 nominations from all rounds (2875 individuals) are analyzed in this article.

Information from each round was entered into the computer database management system called MICRO, available in the Michigan Terminal System based on the AMDAHL/370 computer. Two interconnected files were set up, one for responses and one for nominations, which we have analyzed using cross-tabulation and descriptive statistical methods.

Our analysis of the first three rounds can now be compared to results of the fourth round. Beyond this, our discussion is limited here to the available sample. Work in progress and in press (Kochen, Blaivas, Brumbaugh, and Crickman, 1982) using computer simulation, explores the effect of sample and population size on the results of a procedure like ours.

General Observations

It has been suggested that a "Matthew Effect" (Merton, 1973) or law of "cumulative advantage" (Price, 1976) operates in science, helping those who are prominent to become even more prominent (Allison and Stewart, 1974). This suggests that the distribution of nominations in our study should approximate a form of the theoretical cumulative advantage curve, shown below.

$$f^*(n) = (m+1)\, B(n, m+2),$$

where

$$B(x,y) = \frac{\Gamma(x)\,\Gamma(y)}{\Gamma(x+y)}$$

and $\Gamma(x)$ is the gamma function,

$$\Gamma(x) = \int_0^{\infty} t^{x-1} e^{-t} dt$$

At the end of round 3 the distribution was analyzed (Kochen, Blaivas, and Crickman, 1982b) and found to resemble visually the curve expected from a law of cumulative advantage, but the fit was not statistically significant.

Figure 1 and Table 1 present as a bar graph the distribution of nominations aggregated over all fields and all four rounds. The theoretically expected curve based on the law of cumulative advantage is shown as a solid line. Again, the fit is not significant. Irregularities in the curve suggest that part of the discrepancy may be due to combining distributions of relatively self-contained fields whose absolute size in our sample is not the same. Therefore, we have disaggregated our data to show the distribution in each field separately.

Figure 2 gives a more appropriate representation of the aggregated data. They are plotted on a log-log scale. Circles on the figure correspond to the observed frequencies and crosses to cumulative frequencies. A regression line, $y = -.376 \times +.32$, has been drawn through the observed values. The correlation coefficient for these two random variables is 0.97.

Nominations by Specialty

The nominations whose distribution is shown in Table 1 and Figure 1 are presented in Tables 2a-g and Figures 2b-h to show distribution on a

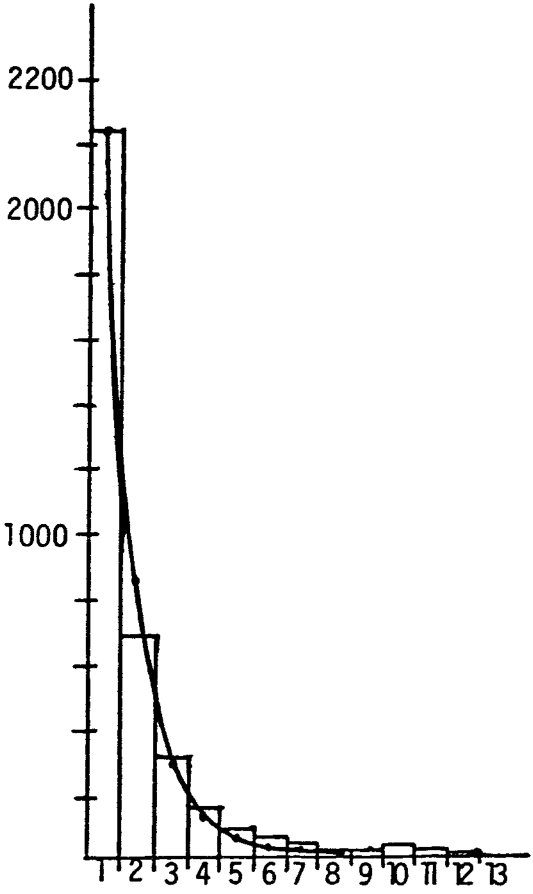

Figure 1: Frequency distribution of the nomination data (histogram) and corresponding cumulative advantage distribution (smooth curve) for all data aggregated over four rounds and all seven specialties. The null hypothesis has been rejected for this distribution.

log-log scale within each of the specialty fields: differential geometry, topology, information science, human systems management, future studies, and polymer chemistry. Regression lines have been fitted through the set of frequencies represented by circles, and the cumulative frequencies, denoted by crosses, were fit by a smooth curve.

TABLE 1
The Distribution of Nominations

Number of Nominations	Number of Nominees
1	2127
2	344
3	159
4	72
5	53
6	34
7	22
8	14
9	9
10	11
11	10
12	1
13	2
14	3
15	5
17	1
18	3
19	1
20	1
21	1
23	2

The linear relationship between the logarithm of the number of nominations and the logarithm of the number of nominees is remarkably strong. In each case the correlation is .95 or higher. Table 2h gives the equations for regressing the logarithm of the number of nominations onto the logarithm of the number of nominees for the seven specialties. An analysis of the residuals indicates that a linear model is appropriate for each area. Therefore, the number of nominations is a power function of the number of nominees. These equations are presented in Figure 2. The slopes for the log-log regression of differential geometry and topology are about –.6, whereas for the other fields they are about –.4. A steep negative slope indicates a greater degree of consensus about who the experts in a given field are, since relatively few people receive a large number of nominations. This result suggests the hypothesis that there is a greater degree of consensus in well-defined, established fields than in newer or more diffuse ones.

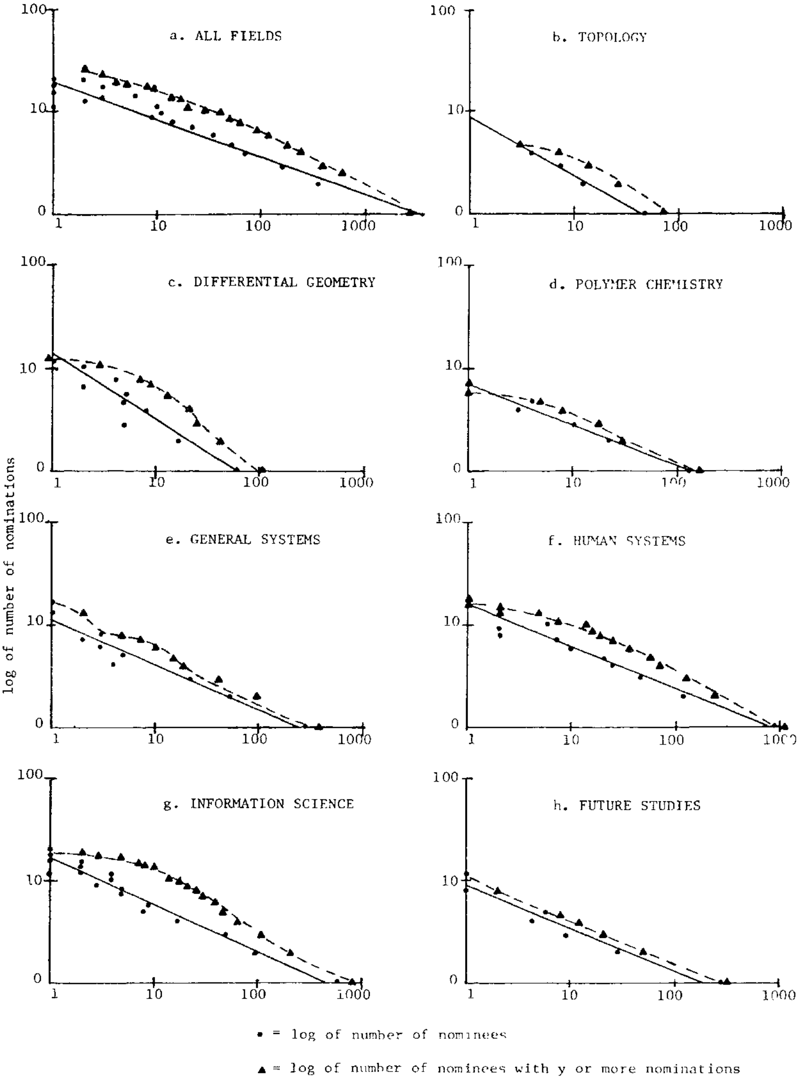

Figure 2: Log of number of nominations.

In Figures 3a-g, bar graphs corresponding to the distribution of nominations in the various specialty fields are shown together with the calculated cumulative advantage curve. In topology, differential geome-

TABLE 2
Distribution of Nominations in Individual Specialty Fields

(a) TOPOLOGY

Number of Nominations	Number of Nominees
1	47
2	12
3	7
4	4
5	3

(b) DIFFERENTIAL GEOMETRY

Number of Nominations	Number of Nominees
1	63
2	17
3	5
4	8
6	5
7	2
8	4
11	2
12	1

(c) POLYMER CHEMISTRY

Number of Nominations	Number of Nominees
1	132
2	22
3	10
4	3
5	4
6	0
7	1

(d) GENERAL SYSTEMS

Number of Nominations	Number of Nominees
1	297
2	54
3	23
4	4
5	5
6	3
7	2
8	3
13	1
17	1

(continued)

try, and polymer chemistry, the three well-defined hard sciences in our sample, deviations from the predicted cumulative advantage curve are insignificant. Of the rest, only general systems theory matches the cumulative advantage curve.

Human systems management, information science, and future studies all deviate significantly, and in the same way. While some individuals stand out with many nominations, a very large proportion—more than would be predicted—are mentioned by one nominator and no others. This suggests that many members of these fields are not aware of each other, or share so few common interests that they do not overlap in their perception of expertise. It has been said that mathematicians are

TABLE 2 (Continued)

(e) HUMAN SYSTEMS

Number of Nominations	Number of Nominees
1	925
2	118
3	45
4	25
5	20
6	10
7	7
8	2
9	2
10	6
11	2
13	3
14	0
15	1
17	0
18	1

(f) INFORMATION SCIENCE

Number of Nominations	Number of Nominees
1	605
2	98
3	51
4	17
5	8
6	9
7	5
8	5
9	3
10	4
11	4
13	2
14	1
15	2
17	2
18	1
19	1
22	1

(g) FUTURE STUDIES

Number of Nominations	Number of Nominees
1	265
2	28
3	9
4	4
5	6
8	1
11	1

particularly aware of their colleagues (Hagstrom, 1965). But within their specialty fields, the topologists and differential geometers seem to have a more coherent common awareness than members of the softer and less established fields.

Since we wish to focus on individuals who received an exceptionally high number of nominations, we single out those who were nominated more than seven times as the category we call "stars." This arbitrary threshold allows us to compare a group of frequently named indi-

TABLE 2i
Log-Log Regressions and Power Functions

y = number of nominations
x = number of nominees with y nominations
Logarithms are with respect to base 10

All Fields

$\log y = 1.32 - .376 \log x$

$y = 20.89x^{-.376}$

Differential Geometry

$\log y = 1.13 - .629 \log x$

$y = 13.49x - 233D - .629$

General Systems

$\log y = 1.06 - .445 \log x$

$y = 11.48x^{-445}$

Information Science

$\log y = 1.25 - .473 \log x$

$y = 17.78x^{-473}$

Topology

$\log y = .961 - .583 \log x$

$y = 9.14x^{-.583}$

Polymer Chemistry

$\log y = .858 - .401 \log x$

$y = 7.21x^{-.401}$

Human Systems

$\log y = 1.18 - .404 \log x$

$y = 15.14s^{-.404}$

Future Studies

$\log y = .936 - .407 \log x$

$y = 8.63x^{-.407}$

viduals with the larger group most of whom received one or two nominations. Obviously, the criterion is more exacting for the disciplines that are small in our sample, with fewer possible nominations. If we were concerned to contrast the stars in different specialty fields, we would have to adjust the definition to reflect the size of each specialty, and consider each specialty separately to correct over-representation of the larger fields in our aggregate data. However, since no significant differences relevant to our discussion of high ranking nominees are revealed by this treatment, we present our data here in aggregate form using the single threshold above seven nominations as the rough definition to single out stars.

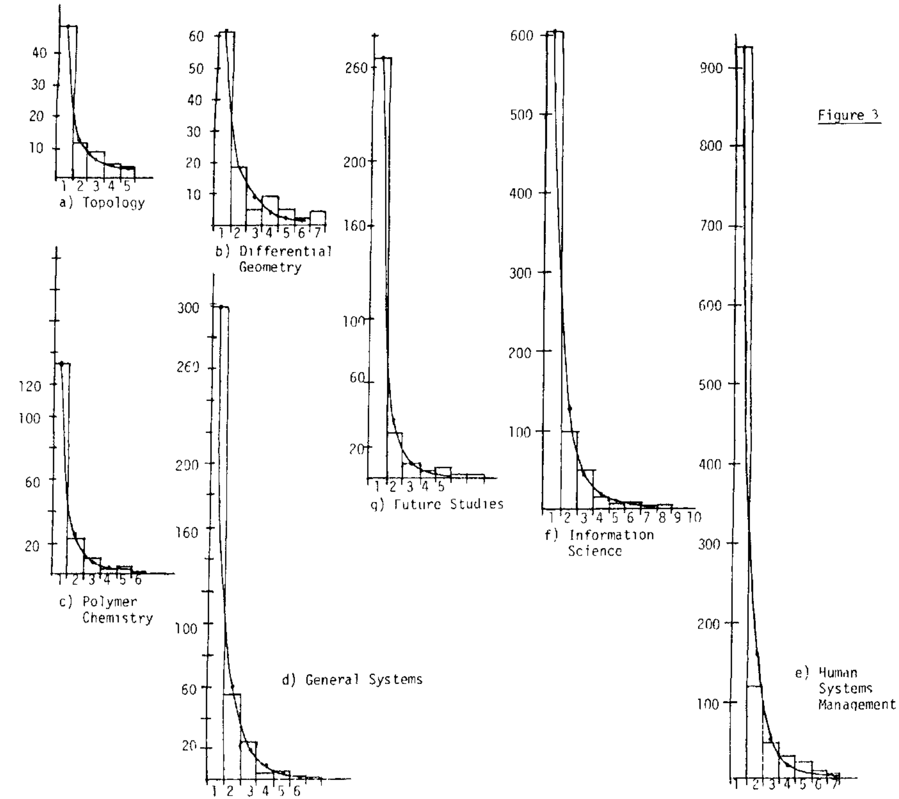
Figure 3
a) Topology
b) Differential Geometry
c) Polymer Chemistry
d) General Systems
e) Human Systems Management
f) Information Science
g) Future Studies

Figure 3.

TABLE 3
Average Number of Nominations per Respondent by Specialty Field

Specialty Field	Average Number Nominated
Differential Geometry	11.5
Topology	10.5
Polymer Chemistry	9.4
Future Studies	9.3
Information Science	8.9
General Systems	8.3
Human Systems	8.3

Respondent Selections by Specialty

In the first two rounds we asked each respondent to give about ten nominations. In subsequent rounds, however, the number of nominations was unspecified. It seemed that the number of names that occurred to the respondent spontaneously might itself be significant, as well as providing a more significant list.

We had speculated that members of the more tightly organized, established fields would be more aware of their coworkers and thus each name a higher number of experts than workers in more diffuse softer fields. Table 3 shows the average number of nominations made by each respondent in the different specialty fields. The difference we expected is present, though not very great: The average number of nominations in each of the three hard, established fields is larger than the average in any of the softer, more diffuse fields. But idiosyncratic factors may be present too. For example, the tendency for future studies nominations to be more numerous than those in human systems management might reflect not closer interconnection among workers, but wider latitude for deciding that various admired experts are really members of this field.

Geographical Distribution of Persons With the Most Nominations

Most of the high-ranking nominees were located in the United States and Britain. Of the 17 who received more than 13 nominations, 13 were working in the United States, 2 in the United Kingdom, 1 in United Kingdom/Canada and 1 in United Kingdom/Ireland. Altogether, of the 64 stars who received over seven nominations, 46 were working in the

United States, 10 in the United Kingdom, 3 in Germany, 2 in Canada, 1 in France, 1 each in Canada/United States, France/United States, Ireland/United States. This is consistent with the distribution of all nominees, stars and nonstars, shown in Table 4. Of all nominations, 70.18% went to scientists working in the United States, 10% to scientists in the United Kingdom, 4.20% to France, 2.78% to Germany, 2.24% to Japan, 2.08% to Canada. The remaining 10.52% were distributed among 38 other countries.

Table 4 shows nominations distributed according to the country specified by the nominators. Sixteen of the nominees were so identified with work in two countries that different nominators did not agree on the nationality of their work. Six of these mixed-nationality cases involved the United States and a second country (Germany, France, Canada, Israel), and four involved the United Kingdom and a second country (Ireland, Canada, United States).

The geographical distribution of nominations was discussed in detail at the end of round three of our study (Blaivas, Kochen, and Crickman, 1981). After four rounds it has extended to a wider area, but retains the characteristics it showed earlier. The prominence of the United States and the United Kingdom probably reflects the high level of scientific activity in these countries, the development of the specific fields we sample, and may also reflect a bias toward American scientists in the earliest rounds of the study.

Stars as Nominators

Is there a difference between the nominations made by stars and the nominations made by others? One might imagine that rivalry or egotism would prevent stars from naming each other. Or, one might suppose that stars form an elite whose members are especially likely to name one another. Neither conjecture is supported by our study.

Comparison with nominations made by nonstars shows very slight difference in this regard. Of the nominations made by stars 12.6% went to other stars, compared to 13.6% of the nominations made by nonstars. Thus stars are not significantly more or less likely to name other stars.

Priority of Nomination of Stars

We might expect that those experts we designate stars, chosen by many nominators, would also be the first individuals to come to mind

TABLE 4
Distribution of Nominations by Country

Country	Number of Nominees	Percentage of Total
Austria	22	.44
Belgium	22	.44
Canada	103	2.08
Chile	5	.10
Columbia	1	.02
Czechoslavakia	7	.14
Democratic Republic of Germany	7	.02
Denmark	21	.42
Egypt	1	.02
Finland	5	.10
France	209	4.22
Germany	138	2.78
Greece	1	.02
Hungary	4	.08
India	9	.18
Ireland	7	.14
Iran	2	.04
Israel	19	.38
Italy	23	.43
Japan	111	2.24
Kenya	1	.02
Luxembourg	1	.02
Mexico	2	.04
The Netherlands	42	.84
Nigeria	1	.02
Norway	44	.88
Oceania	27	.54
Poland	12	.24
Rumania	4	.08
South Africa	3	.06
Spain	15	.30
Sweden	42	.84
Switzerland	11	.22
United Kingdom	495	10.00
United States	3473	70.18
USSR	23	.46
Vietnam	1	.02
Yugoslavia	5	.10
No country specified	35	.70

TABLE 5
Basis of Selection of Stars

	Authority	Contributions	Both
Stars	37	27	264
Nonstars	192	230	932
All	229	257	1196

when our nominators compiled their lists. We did not ask for any deliberate ranking—presumably, names appear on the nominators' lists in the order they were thought of.

We observed that stars' names are more likely to be thought of and listed first. Of stars' names 17.7%, compared to 10.2% of nonstars' names, appear first on a list; 32% of stars' names compared to 20% of nonstars' names appear in first or second place on a list. The stars, who impress many people, also impress people more.

Basis of Selection of Stars

We did not ask our respondents to justify their choice of experts—for the most part, we are not convinced that they would have been able to supply accurate and meaningful explanations. However, beginning with the second round, we did ask one question about the reason for each nomination. For each expert they named, respondents were asked whether their selection rested on the authority and critical judgment of the nominee, or on the contributions to research made by the nominee, or on both of these considerations. The responses are shown in Table 5. About a third of the selections (1682 responses) specified the basis for selection. No reason was specified for the other selections, including all selections made on the first round when the question was not asked.

Overall, the responses show a close connection between perceived contributions and authority. Most of the nominations explained were based on both contributions and authority. Stars were more likely than nonstars to be chosen for both (85% of the stars, 69% of the nonstars).

It is interesting that nonstars were slightly more apt to be chosen for contributions alone than authority alone, while for stars the opposite is true. Wide recognition of an expert implies faith in his or her authority and critical judgment—though it might be debated which comes first.

TABLE 6
Employment of Stars and Nonstars (in Percentages)

	Stars	Nonstars
University	87.65	66.78
Research Institute	4.01	8.53
College	2.95	2.09
Commercial and Manufacturing	2.81	9.96
Public Service	–	5.55
Other	1.9	6.7
Unknown	.68	6.5

Type of Employment

Type of employment is shown in Table 6 for stars and nonstars separately. It appears that the stars are noticeably less diversified: 87.65% hold university positions, compared to 66.78% of nonstars.

Mavericks

Our study of peer judgment within specialties assumes an orderly structure which we recognize is only one aspect of the scientific community. Many scientists whose work enters several fields or who regard themselves as generalists are not so easy to place. Many respondents in our sample were nominated as outstanding experts in a field in which they did not consider themselves to be involved. The following quotations from some prominent scientists explaining why they were nonrespondents are illuminating:

> I am involved in so many fields that it would take much time and space to name all the people I might suggest, depending on the specifics. I would be most reluctant to name just a few "big names" in each area, since there is very little correlation in general between the visibility of a name and the degree of my respect for that individual.

> As an author of a notorious book, I get listed as a practitioner (apparently, even as an expert) in fields I barely know by name. That has apparently happened on this occasion, for by no stretch of the imagination do I belong in any of the fields you list. I probably do belong in two other fields, but I am pretty much a loner in both and I tend to pick up advice from whomever is near at hand.

> My difficulty is that I really do not know what my field is . . . the nature of (my) discipline, as I interpret it, is such that I feel free to roam many different fields. When in graduate school, I was asked what I specialized in, and I replied that I specialized in generalizations. So I find it difficult both to be named as within a network, or even to name those I would regard as individuals to whom I could be linked. If you want to establish a new field called "mavericks," I would try to establish other members of the genus. But since mavericks, by definition, run away from each other, this too might be difficult.

The subsamples of respondents and nonrespondents were similar to each other with regard to location and the institutions with which they are affiliated. These quotations from nonrespondents probably reflect the feelings of many respondents as well. To some extent, therefore, the structured picture of peer relations that we infer from our nomination lists has to be balanced by another approach. The student of science needs to refer to personalized "longitudinal" studies, such as *The Eighth Day of Creation* (Judson, 1979), or *An Imagined World* (Goodfield, 1981) for an approach better suited to the loner, maverick, or interdisciplinarian—an identity which all scientists partake of to some degree.

The role of maverick may be crucial in the dynamics of scientific research: mavericks may be responsible for discovery and paradigm-breaking innovation. We would not ignore this refusal to fit or be fit into place in the terms "loner," "interdisciplinarian," "maverick"—or "weirdo," the title one of our stars and respondents insists on.

Yet whatever their sense of isolation, individuality, and ambiguity, they and their less maverick peers act and exert their effect in terms of structured disciplines and networks. We do not capture the human element in science, but have tried to clarify the medium in which it moves.

Summary and Conclusion

To summarize, this study presents a special approach to the study of scientific elites and the perception of eminence. We have found that the degree of consensus is high in tightly structured, self-contained, and well-defined fields such as differential geometry, topology, and polymer chemistry, whose members distribute their nominations according to the predicted law of cumulative advantage. For newer or less structured, more diffuse fields, there are some highly regarded individuals, but otherwise nominations are more scattered, respondents showing less agreement when they think of the experts in their field, and perhaps not sharing a perception of who is or is not a member of the field. The stability of eminence is perhaps a major difference between hard and soft sciences. If and when a field comes to maturity, it may come to have a recognized consensus about experts whose contributions and judgments hold sway. While this can serve to maintain useful paradigms, it may also be a force resisting replacement of outdated approaches by new ones.

We have tried to contribute to a promising line of inquiry into consensus about expertise, clarifying the difference between patterns of recognition in highly structured and less structured areas of knowledge. For consensus about expertise is one aspect, perhaps not the least important, of the consensus about knowledge itself, which is fundamental to the progress of science.

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