Science grows and cumulates on the research fronts of disciplinary specialties, implying that the most fruitful citation analyses will be those looking at well-defined specialties or subspecialties. The entire literature on centrality and productivity from 1948 to 1979 is used to construct a citation network. Methods are proposed for the analysis of the connective structure of such networks and then applied to the centrality-productivity citation structure. These methods permit identification of the main paths through this literature, distinct intellectual phases, and key articles contributing to the cumulative formation of knowledge about centrality and productivity in social networks. From 1948 through 1956, centrality and program were integrated in a single research program. By the early 1960s, there were two research streams. One focused on measuring centrality in graphs but lost the substantive focus on productivity. The other branch continued the experimental focus on productivity but lost the idea of centrality.

Analyzing the Structure of the Centrality-Productivity Literature Created Between 1948 and 1979

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Connectivity methods (Hummon & Doreian, 1989) for the analysis of citation networks are founded on three simple ideas:

1. Science is a cumulative venture where each new discovery or development depends on some prior work.

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2. The products are generated at the research fronts of specialty fields.
3. The written record, in the form of citation networks, that is left after a research front moves on contains valuable information for understanding the processes of science.

One product of the analysis of citation networks is the widely known image of science as a mosaic of connected networks (Narin, Carpenter, & Berlt, 1972). Each field or specialty has its own citation network, and these networks are loosely linked to form the mosaic of science. The density of citation ties within a specialty or field is likely to be higher than the density of ties connecting it to the rest of the scientific literature.

Small and Griffith (1974) show how citation networks can be mapped into partly overlapping and connected specialties. They start with a network encompassing multiple specialties and delineate the boundaries between the specialties. Starting a search strategy within a specialty also permits the determination of its effective boundary. Ideas are less likely to travel across this boundary in either direction. As research is done within specialties, the citation structure within them reveals, among other things, their cognitive structures.

Bernal (1953) may have been the first to construct a network diagram having nodes as scientific productions (within a specialty) and links representing citations between the productions (Garfield, 1979). Garfield, Sher, and Torpie (1964) constructed such a diagram, calling it a historiograph, and used it to study the unfolding of the DNA literature. For small historiographs, the visual representations of the links in the literature in the form of a network have great appeal. However, if a network has hundreds or thousands of research productions, the visual clarity rapidly disappears. It is important, then, to augment the graphs with some computational procedures for analyzing the structure of the network.

The methods based on depth first search, exhaustive search, and priority search algorithms provide such a tool (Hummon & Doreian, 1989). The historiographs contain the time-dependent linkages between scientific events that underlie the cumulative development of knowledge. Using the DNA research literature as a test case, Hummon and Doreian (1989) were able to delineate the main path through this historiograph. Even though the algorithms are structural, responding only to the structure of citations, all the historically noted major developments in DNA research fell on this main path. Other important work was close to the main path, whereas marginal work was located at the periphery of the specialty.

Although the clarity of the results was stunning, one drawback of that analysis stems from the network published by Garfield et al. (1964) and
repeated in Garfield (1979), having been highly edited. There are 40 nodes in that network, constructed from 69 scientific productions, and it is clear that the research literature of such a field is much larger than this. The Institute for Scientific Information (ISI) account was predicated on the history written by Asimov (1963) in The Genetic Code. Asimov provided the first editing, and the ISI research team provided the second. It is possible that the simple elegance of the main path analysis in the DNA network is an artifact arising through the simplification of a highly complex citation network.

In order to have a serious examination of the utility of connectivity methods, it is necessary to apply them to other citation networks. It is clear that such networks should be larger and, moreover, not pruned in the radical and extensive way that the DNA network was pruned. In order to satisfy the second property, the citation network should be focused on a specialty literature. Moreover, all the relevant research productions must be included.1 Rather than defining “network analysis” as a research area (one that is rapidly growing, is quite highly developed, rests on many disciplines, and has a vast literature), we have elected to focus on the specific part of that literature dealing with centrality and productivity.

The Centrality-Productivity Literature

The Bavelas article “A Mathematical Model for Group Structures” (1948) remains one of the high-water marks in the social network literature. Bavelas’s work is very important for the field for at least three reasons:

1. By varying the communication structure of task-oriented groups, he was able to show how different networks with different structural characteristics would lead to different times for the completion of a specific task. The structure of the network conditions the outputs that result from network processes.
2. He showed also that the structural location of an actor in a network makes a difference, as the actors view themselves, and the group task, differently depending on whether they are at the center or the periphery of the small-group communication structure.
3. The dramatic effects of this research spawned a literature covering at least four decades. Centrality—with or without productivity—became an enduring concern.

Research productions in this literature have some, or all, of the following elements: social psychological small-group processes, experimental design, social organization, business administration, and measurement. Linking the
research together is the common focus on the issue of centrality and its implications for network processes. This research specialty has an obvious starting point in the work of Bavelas (1948, 1950). There is also a clear endpoint to a particular *phase* of research dealing with centrality. Although the intuitive idea of centrality is clear, its precise operationalization has been confused. Freeman (1977, 1979) cleared up the confusion by pointing out three distinct operationalizations of centrality (and pointing out that fruitful use of the concept rests on clear, substantively relevant operationalizations). The data base for the following connectivity analysis is made up of all publications on the topic of centrality and productivity that appeared between the Bavelas and Freeman articles.³

The data base contains 119 articles, technical reports, or books that were created between 1948 and 1979. For the analysis reported here, we have excluded unpublished Ph.D. dissertations and unpublished master’s dissertations but not review papers. We have specifically included many technical reports that, though unpublished, may have been critical to the evolution of this specialty.⁴

Figure 1 provides information on the annual production of the centrality group and the cumulative production through the period from 1948 to 1979. It is clear from the left panel of Figure 1 that most of the production took place during the 1950s and production tailed off after that, particularly in the 1970s. The cumulative production has the general S-curve that Crane (1972) sees as a characteristic of research specialties, although, in part, this is an artifact of plotting cumulative data. There are 632 citation links between the 119 research productions generated by this research group. At the outset (1948) it was not clear which publications would prove to be important, as that can be determined only by later publication activity. We emphasize that science is cumulative and the research literature of an area has structure — the *structure* created by the *evolution* of knowledge.

---

Figure 1: Annual and Cumulative Production by Centrality Group

- **Median Curve**
- **Annual Total**
- **Cumulative Total**
- **Production Period (Years)**
- **Yearly Production**
- **Cumulative Production**

- **Example Text for Figure 1**
  - *Annual Production*
  - *Cumulative Production*
This knowledge is produced in a “theory group” as described by Mullins (1973). Mullins delineates four stages: (1) normal, (2) network, (3) cluster, and (4) specialty or discipline. The most important aspect of the development process for a specialty is the “communication structure” of the research group. It is a straightforward process to show that the centrality-productivity area appears to conform to the stages and processes described by Mullins. This communication is located in the citation network, and these links can be treated solely as citation links in a network of citations (compare Price, 1965). The links suggest the passage of theoretical ideas, experimental design, empirical results, modeling strategies, or any combination of them. There is bound to be random error, some because of suspect citation, but it is highly likely that such errors will be seen as the random events they are.

**Connectivity Methods**

The centrality-productivity literature network is complete, as all known citations among these research productions are included. The network has 119 nodes and 630 links. The relation of this network is the “is cited by” relation instead of the “cites” relations. The “is cited by” network maps the influence of earlier research on later research.

The network of literature on centrality and productivity has the following properties. First, it is completely, though weakly, connected. Second, the network is nearly a directed acyclic graph, or DAG. It contains only two cycles involving productions having the same author or close members in a single geographical location.

Another way of examining connectivity in such a network is to compute the path distances between node pairs. The geodesic, or minimum path, is commonly used to assess how close nodes are to each other, in a graph theoretic sense. Starting from node 1 (the Bavelas article), the maximum geodesic is three, and most geodesics are only one link. The maximum geodesic for the whole network is only five. This high degree of connectedness may be due to the completeness of this citation network.

Geodesics, or minimum paths, are not very relevant to a model of science that assumes knowledge is accumulated step by step. Instead, maximum path lengths or graph tours are of interest. The longest path for the centrality network is, as would be expected, more complex than for the DNA network. This path has 16 links and occurs only once, extending from node 1 to node 131.
Network Connectivity and Search Paths

The exhaustive search algorithm can be used to generate all possible search paths through the network. The count of the number of times a link is traversed by all possible search paths is a measure of the importance of that link. These traversal counts are analogous to the counts of the number of geodesics that run through a node in Freeman’s centrality measure. However, we are concerned with the connectivity of the links rather than the centrality of the nodes. As discussed earlier (Hummon & Doreian, 1989), we compute traversal counts in three ways: search path link count (SPLC), the search path node pair (SPNP), and the node pair projection count (NPPC). Briefly, the SPLC method is a simple count of the number of times links are members of all possible search paths for the network. The SPN method is similar to SPLC except that only search paths that connect particular pairs of nodes are considered. The NPPC method constructs a network of search paths that connect each node pair and then projects the set of all search path networks onto a base network. For this dense centrality network, two links share the highest traversal count of 226,780: the link from node 1 to node 6 and the link from node 130 to node 131 — the first and last links in the network.

The traversal counts can be used to define the main path through a citation network. From any node, we examine the traversal counts of links leaving the node. We choose the link with the highest traversal count and proceed to the next node over that link. We repeat the process until we reach a terminal node. In this manner, we define a path through the network that follows the structurally determined most-used path. We label this path the main path through the network. This link selection technique is an example of the priority first search algorithm, where traversal counts set the priority.

Our intuition is that the main path, selected by the most-used path, will identify the main stream of the literature. Table 1 gives the main path through the centrality literature. It starts with node 1 (the Bavelas article), and one branch finishes with node 131 (the Freeman article), as also shown in Figure 2. However (see note 9), the main path from node 2 terminates in node 118. Although by definition the main path for the whole structure must start at node 1, some attention should be given to paths terminating at node 118.

The early part of this main stream focuses on experimental studies of social psychological processes in task-oriented groups and runs from node 1 through node 50. After node 50, the main path branches into two streams. Using search path link count (SPLC) and search path node pair (SPNP) connectivity methods, the next node in the main path is node 59, as shown
TABLE 1
The Main Paths Through the Centrality-Productivity Literature

1. Bavelas (1948)
6. Leavitt (1951)
9. Heise & Miller (1951)
24. Shaw (1954c)
22. Gilchrist, Shaw, & Walker (1954)
21. Shaw (1954b)
33. Shaw (1955)
50. Shaw & Rothschild (1956)

104. Beauchamp (1965)  95. Cohen (1964b)
131. Freeman (1979)

in the left part of Table 1. However, using the node pair projection methods (NPPC), the next node is node 84, as shown in the right part of Table 1. The relative traversal counts by all three methods are close for these two choices. In our experience, this is unusual, because main path node selections are usually clear. We conclude that this split in the main path is significant.

With the work of Flament (node 59), the left branch of the main path undergoes a radical transformation. Node 59 marks the transition from a focus on the implications of centrality for group productivity to an explicit concern with measurement of centrality. Following node 59, all articles focus...
on the definition and measurement of centrality. This was a noteworthy
transition. Within Bavelas’s work there is a major ambiguity about centrality.
As Freeman (1979) points out, degree centrality, nearness centrality, and
betweenness centrality are distinct and need to be distinguished if the
structural consequences of centrality are important. Throughout the early
phase of the main path, the major thrust and inventiveness came in the design
of variations of the fundamental experiment. However, these researchers did
not probe deeply the meaning of centrality.

The right branch in the main path after node 50 continues the experimental
study of productivity in small groups and culminates at node 118. As time
passed, the work of these experimentalist exhibited less and less concern with
centrality and, more generally, with the structural properties that led to their
results. The experimental structures were assigned names, and the results
were couched in terms of the relative performance of “wheels,” “stars,” and
so forth. In effect, after the work of Shaw and Rothschild (node 50), the earlier
tradition that integrated work on centrality with work on productivity split
into two research streams. One group worked on centrality while the other
worked on productivity.

Another way to examine the structure of the main path or paths through
a citation network is to construct the network of main paths. We compute a
main path from every nonterminal node in the network. We then use the links
in these paths to define the network of main paths. Figure 2 presents part of
this network, whereas using NPPC yields Figure 3. Seventy percent of all
nodes have main paths that end at either node 131 or node 118.

**Structural Equivalents**

We also analyzed the centrality literature network for structural equiva-
lents. If two articles cite the same earlier articles, then, in the sense of
bibliometric coupling, they are equivalent. Alternatively, if they are cited by
the same other articles, they are, in the cocitation sense, equivalent. Of
course, research productions can be equivalent in both the bibliometric
coupling and the cocitation sense. We computed the extent of nonequivalence
as measured by Euclidean distance and then clustered the nodes of the
network. An icicle plot (Kruskal & Landwehr, 1983) was used to examine
the clustering results.

Using the icicle plot, we split the set of articles into three groups. All the
members of the first group are either unpublished, not written in English, or
both. Their location in the icicle plot shows that they are peripheral to the
determination of a main path. Moreover, they are irrelevant to the development of this scientific field. As Mullins (1973) points out, a theory group needs a geographical location (or an intellectual one) where a group of scholars freely exchange papers and provide mutual criticism. In terms of the recognition in defining a specialty, it is clear that published work is more important than unpublished work even if the unpublished work helps create a cultural milieu within which science can be conducted.

The second group of articles shows some kind of coherence in the sense of the stepping-up pattern to the right. These works form the bulk of the literature and are the “journeyman” products in that literature. They are more relevant than the unpublished productions, but very little distinguishes them concerning the contribution in creating scientific knowledge.

The third group of articles is not so much a cluster, in the cluster analytic sense, but a group containing most of the discontinuities in the icicle plot. All of the main path nodes are found within this third group. This pattern of main path nodes and significant jumps in clustering levels describes the structural nonequivalence properties of the third group.

If this interpretation is correct, then nodes on the main path are quite unlike other nodes in the network. They demarcate important transitions in the
literature and represent the critical blocks from which the specialty generates its knowledge.\textsuperscript{12}

This analysis suggests an image of the literature of a specialty as a watershed in an ecological system. Articles belong to a particular niche and funnel knowledge into the streams of the literature. Ideas that are not picked up quickly within a watershed are not absorbed, and nothing distinguishes them from one another. This seems to be the fate of the works in Group 1. Other items may be important as minor tributaries within a watershed, which characterizes most of the work in Group 2. Finally, there are the main waterways of each watershed. Ideas near the main path are picked up quickly and augment the main stream.

The major knowledge bases for this (centrality-productivity) specialty can be found in social psychology, communications, and organization theory. We coded each research production according to the presence or absence of these properties. We found no differences in the relative distribution of these characteristics across the different cluster groups. Further, the presence or absence of experimental methods does not distinguish the three cluster groups. However, when we consider the presence or absence of graph theory, the three groups have different distributions; see Table 2.
The presence of graph theory intensifies through the three identified groups, so that graph theory enjoys the highest relative frequency within the set of publications seen as crucial. We have seen (Table 1) that the centrality-productivity literature split into separate literatures. The branch continuing the experimental approach to productivity, but without the structural concept...
Hummon et al. / CENTRALITY-PRODUCTIVITY LITERATURE

TABLE 2 Continued

<table>
<thead>
<tr>
<th>Decade</th>
<th>Published</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>1940-49</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4.17%</td>
</tr>
<tr>
<td>1950-59</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>79.17</td>
</tr>
<tr>
<td>1960-69</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>16.67</td>
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<tr>
<td>1970-79</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>100.1%</td>
</tr>
</tbody>
</table>

$\chi^2(3) = 13.20$  Prob > $\chi^2 = 0.004$

(3) Distribution of Publication Outcome by Group

of centrality, appears to have run its course. As such, it offers no foundation for future work. The other branch, whose primary focus was on centrality, almost to the exclusion of substantive concerns, seems to have prevailed. This is not a triumph of technique over substance, as both branches of the main path lost a key concern. Rather, with centrality conceptualized clearly, the way is clear to examine its substantive implications.

Summary

Connectivity methods (Hummon & Doreian, 1989) provide a coherent way of examining the connective structure of scientific citation networks. When these methods are used for the complete set of productions dealing with centrality and productivity, a very clear main path is found. It starts with an article by Bavelas in 1948 and follows a course where centrality and productivity are both considered. By the late 1950s, this main path had split into two distinct parts. One branch continued the experimental examination of productivity but lost the conception of centrality as a structural property. The other path underwent a transformation to the use of graph theory for defining and measuring centrality and thereby lost the substantive concern
with productivity. By establishing the main path with a bifurcation, connectivity methods have revealed distinct intellectual phases in the study of centrality and productivity.

An appropriate next step is to consider the centrality literature published since 1979 to delineate the main paths from the Freeman article. Our intuition is that at least two branches will be seen. One will explore the substantive implications of centrality across a wide range of social phenomena; the other will continue the graph theoretical work. The former branch will reintegrate a structural concept of centrality with issues of substance. Both branches can be studied with the citation data from 1979 onward or with the combination of the pre- and post-1979 data.

APPENDIX

Productions of the Centrality-Productivity Literature

Note: For each research production the last number, in parentheses, is its identification number.

Bavelas, A.
1948 A mathematical model for group structures. Applied Anthro. 7:16-30. (1)

Bavelas, A.

Bavelas, A. and D. Barrett

Beauchamp, M.

Burgess, R. L.

Burgess, R. L.

Burgess, R. L.

Burgess, R. L.

Carzo, R.
1963 Some effects of organization structure on group effectiveness. Admin. Sci. Quart. 7:393-424. (91)
Christie, L. S.

Christie, L. S.

Christie, L. S. and R. D. Luce

Christie, L. S., R. D. Luce and J. Macy

Christie, L. S., R. D. Luce and J. Macy

Cohen, A. M.

Cohen, A. M.

Cohen, A. M.

Cohen, A. M.
1964b Predicting organization in changed networks II. Journal of Psych. 57:475-499. (94)

Cohen, A. M.
1964c Predicting organization in changed networks III. Journal of Psych. 58:115-129. (95)

Cohen, A. M.

Cohen, A. M. and W. G. Bennis

Cohen, A. M. and W. G. Bennis
1960b A model predicting the influence of previous experience on the communication systems established by problem-solving groups. Boston U. Human Relations Center. Technical Report. (73)

Cohen, A. M. and W. G. Bennis

Cohen, A. M. and W. G. Bennis
Cohen, A. M., W. G. Bennis and D. Briggs
1960 A partial test of a model predicting the influence of previous experience on the communication systems established by problem-solving groups. Boston U. Human Relations Center. Technical Report. (76)

Cohen, A. M., W. G. Bennis and G. H. Wolkon

Cohen, A. M., W. G. Bennis and G. H. Wolkon
1961 The effects of continued practice on the behaviors of problem-solving groups. Sociometry. 24:416-431. (84)

Cohen, A. M., W. G. Bennis and G. H. Wolkon

Cohen, A. M. and J. R. Foerst
1968 Organizational behavior and adaptation to organizational change of sensitized and repressor problem-solving groups. Journal of Personality and Social Psych. 8:209-216. (118)

Cohen, A. M., P. E. Rosner and J. R. Foerst

Collins, B. E. & B. H. Raven

DeSoto, C. B.

Doktor, R. and S. Makridakis

Faucheux, C. and K. D. MacKenzie

Faucheux, C. and S. Moscovici

Flament, C.
1956a Changements de rôles et adaptation latâche dans des groupes de travail utilisant divers reseaux de communication. Année. Psych. 56:411-432. (42)

Flament, C.

Flament, C.
1958a La performance des groupes de travail rapports entre la structure de l'activité et celle du le seau de communication. Année Psych. 58:71-89. (58)

Flament, C.
Flament, C.

Flament, C.

Flament, C.

Flament, C.

Freeman, L. C.
1977 A set of measures of centrality based on betweenness. Sociometry. 40:35-41. (130)

Freeman, L. C.

Gilchrist, J. C., M. E. Shaw and L. C. Walker

Glanzer, M. and R. Glaser

Guetzkow, H.

Guetzkow, H.
1954 Organizational development and restrictions in communications. Pittsburgh Graduate School of Industrial Administration, Carnegie Institute of Technology. (27)

Guetzkow, H.
1960 Differentiation of roles in task-oriented groups, in D. Cartwright and A. Zander (eds.) Group Dynamics: Research and Theory (2nd ed.). Evanston, Ill.: Row, Peterson. 683-704. (75)

Guetzkow, H. and W. R. Dill
1957 Factors in the organizational development of task-oriented groups. Sociometry. 20:175-204. (53)

Guetzkow, H. and H. A. Simon

Harshberger, D.

Heise, G. A. and G. A. Miller
Hirota, K.

Karaneff, V. T.

Lanzetta, J. T. and T. B. Roby

Lanzetta, J. T. and T. B. Roby
1956b Group performance as a function of work distribution and task load. Sociometry. 19:95-104. (45)

Lanzetta, J. T. and T. B. Roby

Lawson, E. D.
1964a Reinforced and non-reinforced four-man communication nets. Psychological Reports. 14:287-296. (99)

Lawson, E. D.
1964b Reinforcement in group problem-solving of arithmetic problems. Psychological Reports. 124:703-710. (100)

Lawson, E. D.
1965 Change in communication nets, performance, and morale. Human Relations. 18:139-147. (103)

Leavitt, H. J.

Leavitt, H. J.

Leavitt, H. J. and K. E. Knight

Luce, R. D.
1951 The theory of networks. Group Network Laboratory. Research Laboratory of Electronics, Massachusetts Institute of Technology. (10)

Luce, R. D., J. Macy, L. S. Christie and D. H. Hay
1953 Information flow in task-oriented groups. Research Laboratory of Electronics, Massachusetts Institute of Technology, Report No. 264. (19)

MacKenzie, K. D.

MacKenzie, K. D.

Macy, J., L. S. Christie and R. D. Luce

McWhinney, W. H.
1954 Simulating the communication network experiments. Behavioral Science 9:80-84. (97)
McWhinney, W. H.
1964 Self organizing systems. Ph.D. thesis. Pittsburgh: Graduate School of Industrial Administration, Carnegie Institute of Technology. (96)

Mohanna, A. I. and M. Argyle
1960 A cross-cultural study of structural groups of unpopular central members. Journal of Abnorm. and Social Psych. 60:139-140. (76)

Morrisette, J. O.

Morrisette, J. O., W. H. Pearson and C. W. Switzer

Morrisette, J. O., S. A. Switzer and C. W. Cranne

Moxley, R. L. and N. F. Moxley

Mulder, M.
1955 De invloed van de communicatie—structuur op het gedrag van groepen. Mens en Onderneming. 9:456-469. (37)

Mulder, M.

Mulder, M.

Mulder, M.

Mulder, M.

Mulder, M.

Mulder, M.
1960b The power variable in communication experiments. Human Relations. 13:241-256. (78)

Nieminen, J.
1973 On the centrality in a directed graph. Social Science Research. 2:371-378. (122)

Nieminen, J.

Roby, T. B. and J. T. Lanzetta

Roby, T. B. and J. T. Lanzetta
1956b Work group structure, communication, and group performance Sociometry. 19:105-113. (48)
Roby, T. B. and J. T. Lanzetta

Roby, T. B. and J. T. Lanzetta
1957b A laboratory task for individual and group problem-solving behavior. Air Force personnel and Training Center Research Report.

Rogers, D. L.

Rogers, E. M. and R. Agarula-Rogers

Rogge, G.

Sabidussi, G.
1966 The centrality index of a graph. Psychometrika. 31:581-603. (109)

Shaw, M. E.

Shaw, M. E.
1954a Group structure and the behavior of individuals in small groups. J. Psych. 38:139-149. (23)

Shaw, M. E.
1954b Some effects of problem complexity upon problem solution efficiency in different communication nets. J. Exp. Psych. 48:211-217. (22)

Shaw, M. E.

Shaw, M. E.
1955a Communication patterns in small groups Office of Naval Research, Research Reviews—11-15. (Review) (34)

Shaw, M. E.
1955b A comparison of two types of leadership in various communication nets. J. Abnorm. Soc. Psych. 50:127-134. (33)

Shaw, M. E.
1956 Random vs. systematic distribution of information in communication nets. J. Pers. 25:59-69. (49)

Shaw, M. E.

Shaw, M. E.
1959 Acceptance of authority, group structure and the effectiveness of small groups. J. Pers. 27:196-210. (65)

Shaw, M. E.
Shaw, M. E. and G. H. Rothschild

Shaw, M. E., G. H. Rothschild and J. F. Strickland

Shelley, M. W.

Shelley, M. W. and J. C. Gilchrist
1958 Some effects of communication requirements in group structures. J. Soc. Psych. 48:37-44. (57)

Shure, G. H., M. S. Rogers, I. M. Larsen and J. Tassone
1962 Group planning and task effectiveness. Sociometry. 25:263-282 (89)

Smith, S. L.
1950 Communication pattern and the adaptability of task-oriented groups: An experimental study. Group Networks Laboratory, Research Laboratory of Electronics, Massachusetts Institute of Technology. (3)

Smith, S. L.
1951 Survey of some experiments in group communication. Group Networks Laboratory of Electronics, Massachusetts Institute of Technology. (5)

Snadowsky, A.
1972 Communication network research: An examination of controversies. Human Relations. 25:283-306. (121)

Snadowsky, A.

Trow, D. B.
1957 Autonomy and job satisfaction in task-oriented groups. J. Abnorm. Soc. Psych. 54:204-209. (51)

Walker, L. C.

Watson, D. and B. Bromberg

Notes

1. There is, of course, an inherent ambiguity in the definition of a field, or specialty, at this point. Even the DNA literature could be seen as resting on multiple disciplines. All the scientific events in the network were coded to the extent that they belong in protein chemistry, genetics, nucleic chemistry, and microbiology. A case could be made for conducting a separate analysis within each of these disciplines making up a multidisciplinary approach to the study of DNA.

2. The differential completion times indicate differential group productivities — hence the use of centrality and productivity to designate this area.
3. We note, for future reference, that there has been a vast literature on centrality following the Freeman article. We think that the Freeman article provides a solid foundation for the next phase of centrality research, just as the Bavelas article did in the beginning. In principle, the centrality literature extending beyond the 1979 article can be analyzed by itself or in conjunction with the data base considered here.

4. We note that when we excluded review articles in the network, all the major findings remained unchanged.

5. This differs from the structure of the DNA network. The latter contained subgraphs that were mutually unreachable.

6. Not surprisingly, both citation networks we have examined are “near” DAGs.

7. Our results show that the centrality network is even more closely linked than the DNA network.

8. In addition to a conventional reference section, we have appended a complete list of the research productions contained in our citation data set. Some items are on both lists. Henceforth we will use the ID number in the appendix to refer to a data node in describing our results. Citations to our reference section will take the usual author and date form.

9. For each link of the main path network, there must be a corresponding link in the initial citation network. Note, however, that there is only one link out of a node in the main path network. This link is chosen by virtue of having the highest traversal count at the node. Thus, the link at article 1 in Figure 2 with the highest traversal count is to article 6. For defining main paths, nodes 2, 3, 4, and 5 are now all available as the start point for a main path from them. Node 2 starts another path where the first link is to node 3: this path will continue from node 3 (going to node 10), so node 3 cannot start a main path. Nodes 4 and 5 start main paths; however, they start paths that quickly lead to an extant main path.

10. We have omitted from Figure 2 nodes with paths that do not end with these two articles. These omitted nodes generate six more main paths, each involving one to six nodes. These residual paths represent individuals or groups who cite their own work, and that work was never cited by others in the field.

11. The split into two terminal nodes in Table 1 can be seen as a composite from Figure 2 and 3.

12. Consistent with this argument, the cross-tabulation of the identified groups by publication status is:

<table>
<thead>
<tr>
<th>Publication Status</th>
<th>Peripheral</th>
<th>Identified Group</th>
<th>Crucial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpublished</td>
<td>45%</td>
<td>Minor Importance</td>
<td>2%</td>
</tr>
<tr>
<td>Published</td>
<td>55%</td>
<td></td>
<td>98%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>((N = 31))</td>
<td>((N = 30))</td>
<td>((N = 58))</td>
<td></td>
</tr>
</tbody>
</table>

For this table, \(\chi^2(2) = 26, p = 0\). The proportion of published papers is highest for the crucial set of articles and lowest for the peripheral, as would be expected. Through time, the proportion of papers published each decade climbs steadily from 50% to 100% (\(\chi^2[3] = 13.2, p = .004\)). Publication counts in the determination of a main path, whereas remaining unpublished means a paper will, most likely, be irrelevant to the growth of a field.

13. In addition, the “productivity branch” of the literature may have been sustained by the energy of a single scholar.
References


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