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MIGRATION PATTERNS OF U. S. PH. D. S AMONG DISCIPLINES AND SPECIALTIES*

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Patterns of migration among disciplines and specialties are examined using data from a large survey of U. S. Ph. D. s in a broad range of fields. Mappings of scholarly fields are derived from the migration patterns and these mappings are largely consistent with results from previous studies using citation flows and other measures of field similarities. Migration patterns suggest that there are two boundaries dividing the fields in this analysis, and that hierarchical relations among disciplines are weak or absent. In contrast, specialties within a discipline are more likely to exhibit structural hierarchies.

Introduction

The rapid growth of scholarly activity over the past two centuries has been accompanied by its increased differentiation into disciplines, specialties, and even subspecialties. Although the processes producing this differentiation have received a fair amount of attention,[1] few researchers have systematically examined the extent and pattern of the relationships between these units of scholarly activity. This is surprising in view of past recognition of the importance of this topic. Both *Comte* and *Durkheim* identified the proliferation of scientific fields as a possible source of the disintegration of science. *Comte* viewed it as one reason for the development of the "positive philosophy," and *Durkheim* used it to illustrate the anomic division of labor.[2] More recently, *Kuhn* has argued that studying the structural relations among scientific fields is a prerequisite for analyzing many other topics in the history and sociology of science.[3] This paper addresses the structural relations between units of scholarship in the United States. It does so by analyzing scholars' intellectual migration patterns between disciplines and specialties within comtemporary scholarship.

Two concepts guide most approaches to studying structural relations between scholarly fields: proximity and hierarchy. The *proximity* of two fields usually refers

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to the extent to which their theories and methods overlap. Thus, biochemistry is more proximate to molecular biology than to history. Development of measures of proximity is a first step in producing "maps" of scholarly activity and in determining clusters of similar scholarly fields.[4] Scholarly fields are *hierarchically* related insofar as one is seen as more fundamental than the other. This idea dates back at least to *Aristotle,* who in the *Posterior Analytics* sets out formal criteria by which one field may be judged as being "prior to" another.[5] Contemporary discussions of the idea, however, usually follow *Hagstrom*'s definition of hierarchy in terms of asymmetric information flows.[6] For example, elementary particle physics is often characterized as being more fundamental than other areas of physics because it supplies more information to each of the other areas than it receives from them. *Hagstrom* offers a number of examples of purported asymmetries in various scientific fields, and argues that they are the basis of prestige differences among fields.

When one group of scholars relies heavily on the concepts and techniques of another group, it is likely that the former will heavily cite the publications of the latter. Thus, attempts to study information flows among scholarly fields usually employ some form of data on citation flows.[7] But two significant difficulties have hindered the use of citation-flow data to answer questions about structural relations among fields. First, the source of nearly all citation-flow data, the Institute for Scientific Information, divides its data into three separate files: one for the natural sciences and mathematics (used for compiling the *Science Citation Index*), another for the behavioral sciences (used for compiling the *Social Science Citation Index*), and a third for the arts and humanities (used for compiling the *Arts and Humanities Citation Index*). Thus, studies of the scientific literature to date have focused either on the natural sciences and mathematics or on psychology and the social sciences, rather than encompassing the natural and behavioral sciences.[8] Second, citation index data consist of information about specific articles so these data must be aggregated for entire disciplines or specialties before citation flows between such fields can be studied. This is a formidable task. As a result, those who analyze citation-flow data tend to focus on whether they reveal patterns consistent with common preconceptions of the boundaries of scientific fields rather than on the nature of citation flows across such bondaries.[9]

A possible alternative to using citation flows to study the relationships between scholarly fields is to use data on the migration of scholars between them.[10] Though migration patterns are less closely connected to flows of information than are citation flows, there are reasons to expect migration patterns to reflect information flows. Because scholars sometimes switch fields in order to gain competitive advantages in the quest for priority and recognition,[11] migration patterns should reflect cognitive relations among fields. For example, when two fields exchange large numbers of scholars, the fields probably share important cognitive commonalities.[12] Similarly, when large numbers of scholars trained in one field migrate to a second, but few from the second migrate to the first, it is likely that the theories or methods of the first have significant applications in the second but not vice versa. Thus, the flow of ideas from one field to another is often accompanied by the movement of scholars in the same direction.[13] Indeed, such movement appears to be a common factor in the emergence of new fields.[14]

Data on the migration of scholars among fields of scholarship are less subject to the technical difficulties noted above for citation-flow data. First, migration flows of scholars are much smaller in number than citation flows among papers, and it is therefore easier to obtain very broad coverage of fields within a single data file. Second, scholars can be queried directly about their primary fields of interest thereby avoiding potentially arbitrary decisions on how to aggregate them into fields.

Of course, the magnitudes of migration streams among fields are affected by forces other than the fields' intellectual proximities and hierarchies, such as their relative sizes and changes in these sizes over time. A recent study of the migration of German academic scientists elaborates this point in suggesting that labor market forces are the most important causes of interfield migration.[15] Fortunately, techniques are available for taking into account the relative sizes of fields when analyzing interfield migration.[16] In addition, the analyses of citation flows provide a partial gauge to assess the adequacy of using migration flows to analyze structural relations among fields. To the extent that the two kinds of flows show consistent patterns, one can be more confident of the picture of field relations that the migration-flow data suggest.

Data and methods

This study uses data from the 1981 Survey of Doctoral Recipients (SDR) carried out by the National Research Council's Office of Scientific and Engineering Personnel (OSEP). The survey's sampling frame included all those who had earned doctorates in the sciences, engineering, and humanities during 1938–80 and who were residing in the U.S. in February 1981. From this sampling frame the OSEP drew a random sample stratified by year of doctorate, field of doctorate or employment, sex, race/ethnicity, and citizenship. A 70-percent response rate yielded information for 39 547 respondents, and analyses of possible response bias for the 1981 and previous SDRs suggest that they are representative on their target populations.[17]

For the purposes at hand it is desirable to omit those who are unlikely to be engaged in research and those whose migration patterns are likely to have been determined by the organizational authority of others rather than by their own choices. Thus, I excluded persons with positions in organizational settings that tend to discourage self-directed research,[18] and those who reported that they held positions that were predominantly administrative in nature. The resulting sample consists of 18 377 respondents.

The OSEP used different sampling fractions to obtain reliable data for various subcategories of scholars in its survey. Thus, in order to estimate the actual numbers of scholars who follow a particular migration path, one must weight each of the respondents by his or her sampling fraction. This weighting procedure yields estimates of the sizes of migration streams for the 221 300 Ph.D.s who constitute the population of interest in this analysis.

The 1981 SDR asked each respondent to indicate from a list of 207 "specialties" both the major field of his or her doctorate and that of his or her current employment.[19] The analyses reported below are based on crosstabulations of the responses to these two questions. A large number of possible methods for analyzing data in this form exist.[20] In my analysis, I first produced simple graphs or "maps" of the major migration streams of Ph.D.s between fields. To do this I used multidimensional scaling analysis (MDS) of measures of the dissimilarity of fields' migration patterns. This technique (the same as that Blau and Duncan used to study the flows of workers between occupational categories) yields two kinds of information.[21] First, it indicates the number of spatial dimensions needed to represent adequately the fields as far as similarities in their migration patterns are concerned. Second, it identifies groups of fields that exhibit similar migration patterns.

Next I compared the sizes of each of the migration streams among the fields in a given analysis with the sizes predicted by *Goodman*'s "quasi-perfect mobility" (QPM) model.[22] The QPM model posits that, except for the immobility represented by the main diagonal of a mobility matrix, movement within the matrix is solely a function of the sizes of the origin and destination categories. It is thus possible to determine the extent to which the migration streams in a matrix exceed what would be expected on the basis of field sizes and their changes over time.

Finally, I constructed graphs showing (1) the relative field positions yielded by the MDS analyses, and (2) the disproportionately large migration streams. Disproportionately large migration streams are those that are at least two times larger than predicted by the QPM model.

Results

Migration between large disciplines and disciplinary groups

Examining the migration streams between large disciplines and groups of smaller ones provides an overview of the major patterns of movement of scholars. To identify them, I began by constructing 17 relatively homogeneous categories from OSEP's 14 general category classification.[23] and then crosstabulated respondents' Ph.D. and current employment categories. As noted above, respondents in my analyses are weighted by their sampling fractions so as to produce estimates of the population frequencies in each cell of a 17-by-17 table.

Of the 272 off-diagonal cells in this table,[24] 111 contain zeros. Thus, even when scholarly fields are broadly defined, no one travels many of the possible migration paths between them. Moreover, the frequencies in the off-diagonal cells of the table are highly skewed, their mode, median and mean being 0, 14 and 103, respectively. Thus, the table consists of many streams with few migrants and a few streams with large numbers.

In order to represent the crosstabulation graphically, I computed both "inflow" and "outflow" percentages for each category and then calculated matrices of dissimilarity coefficients for each of the two types of percentage. Each of the two matrices of dissimilarity coefficients was then submitted to a MDS analysis program. In both cases the Kruskal stress coefficients for three, two and one dimensions suggested that a two-dimensional solution is appropriate,[25] and in both cases the 17 general fields were arranged in a roughly triangular pattern with one vertex consisting of history and the arts and humanities; the second consisting of experimental biology, other biology and medicine; and the third consisting of mathematics, computer science and astronomy. Figure 1 portrays the relative positions of the fields in the MDS analyses and depicts the disproportionately large migration streams among the fields by arrows between them. Solid arrows denote streams that are at least four times larger than predicted by the QPM model and dotted arrows represent streams that are between two and four times larger. It should be noted that the positions of fields in Fig. 1 do not exactly reproduce their relationships in the MDS analyses. The latter vary slightly depending on whether inflow or outflow percentages are analyzed and depend to some extent upon random sampling variation. In addition, the positions of fields that were quite close together in the MDS analyses, for example, history and the arts and humanities, are separated slightly in Fig. 1 for greater graphic clarity. These small distortions of the MDS results are not significant since we are primarily interested in the broad patterns shown by the migration streams.

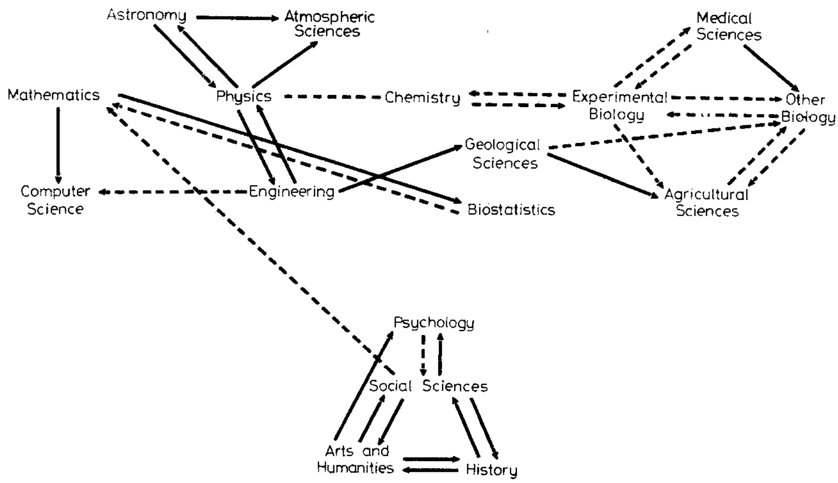

Fig. 1. Migration streams among large disciplines and disciplinary groups. Migration stream > 4 times predicted by QPM model ——→; Migration stream ⩽ 4 and ⩾ 2 times predicted by QPM model - - -→

The results portrayed in Fig. 1 indicate that the 17 general areas of scholarship are grouped into two clusters: the natural sciences and mathematics, and the behavioral sciences and humanities. The former cluster is arrayed along a dimension ranging from mathematics, astronomy and computer science at one pole to the life sciences at the other pole. Physics and mathematics are central fields among the first group, and experimental biology is a central field among the second group. Chemistry and the geological sciences occupy important structural positions as intermediaries between the physical and life sciences. The patterns of disproportionate migration flows do not suggest that the fields in the first cluster form even a fairly weak hierarchy since many disproportionate flows are reciprocated and those flows that are unreciprocated do not form transitive patterns.

Fields in the behavioral sciences and humanities cluster disproportionately tend tc exchange scholars among themselves rather than with fields in the first cluster. The only exception to this rule is a flow from the social sciences to mathematics. A closer inspection of the origin and destination specialties of the scholars in this migration stream reveals that 75 percent specialized in "social statistics" for their Ph.D.s and are currently working in "mathematical statistics". Thus, the only significant link between the behavioral sciences and the fields in the first cluster stems from the prominence of statistical methods in the former. Once again, the pattern of flows within the behavioral sciences and humanities cluster do not suggest that the fields are arranged hierarchically.

How well do these results conform to previous work on the structure of scholarly fields? This work has been of two general types: (1) structural analyses based on citation flows between papers, journals, etc., and (2) analyses of the similarities between disciplines in terms of various attitudes and behaviors of their members.[26]

Most of the work on citation flows has focused on the natural sciences, and therefore can be compared only to the upper part of Fig. 1. In their study of highly cocited papers in the natural sciences, *Griffith* et al. found that such papers tend to be in three general areas: physics, chemistry and biomedicine. They also fund a relatively weak connection between physics and biomedicine and stronger links between chemistry and both biomedicine and physics.[27] *Griffith* et al. noted that in their analysis, chemistry seems to play an important role in integrating much of natural science. In their research on citation flows among journals in the natural sciences and mathematics, *Narin* et al. found that the fields could be spatially represented by the sequence mathematics, physics, chemistry biochemistry and other biomedical sciences, an ordering consistent with the upper part of Fig. 1.[28] Like the researchers studying cocitation clusters, they also found that chemistry connects the physical and life sciences.

Most studies of similarities among fields have been based on a greater range of fields and have found that three dimensions are required to represent them spatially.[29] The three dimensions are a "hard-soft" dimension, which has been interpreted as corresponding to variation in consensus across fields,[30] a "life system-nonlife system" dimension, and a "pure-applied' dimension. The vertical dimension of Fig. 1 appears to correspond to the hard-soft distinction, and the horizontal dimension to the life-nonlife system distinction. The lack of a pure-applied dimension in Fig. 1 is somewhat surprising since the present study includes fields that loaded on the applied end of this dimension in the previous studies: computer science, engineering disciplines, and agricultural sciences. Apparently scholars' migration patterns are affected more by cognitive similarities among fields, as these are reflected by the two dimensions of Fig. 1, than by whether a field is oriented primarily toward the application of knowledge.

If cognitive similarities are the basis of the arrangement of fields in Fig. 1, it seems inappropriate to identify its vertical dimension as consisting of variation in consensus across fields. A more parsimonious interpretation is that fields in the upper section tend to study physical and chemical phenomena while those in the lower section tend to study social, psychological and cultural phenomena. This interpretation is more parsimonious because it employs one principle, cognitive similarity, to account for the dispersion of fields in Fig. 1 rather than two, as the studies cited above suggest. Thus, rather than generating the vertical dispersion of fields in Fig. 1, variation in consensus is probably only roughly associated with the patterns of intellectual commonality that do generate it.

Thus, it is apparent that the results in Fig. 1 are consistent with the argument that scholars' migration patterns are primarily affected by fields' degrees of intellectual proximity. The close correspondence between the migration patterns and the findings of studies based on citation flow data is especially striking in this respect. This is not to deny that employment and research opportunities play an important role in scholarly migration; only that such opportunities themselves appear to be largely dependent on intellectual proximity. Several of the fields portrayed in Fig. 1 are highly aggregated groupings of disciplines, however, so a more fine-grained analysis of them is in order. In the following sections, I present such analyses for (1) the behavioral sciences, arts and humanities sector in Fig. 1, and (2) the life sciences sector.

Relations among the social sciences and humanities

The MDS analysis results for the behavioral sciences and humanities suggested that these fields can also be adequately represented in two dimensions,[31] and identified three extreme groups of fields: the first consists of languages and literature and the performing arts; the second of economics; and the third of psychology and sociology. Figure 2 summarizes the results of the MDS analyses and shows the disproportionate migration streams between these fields.[32]

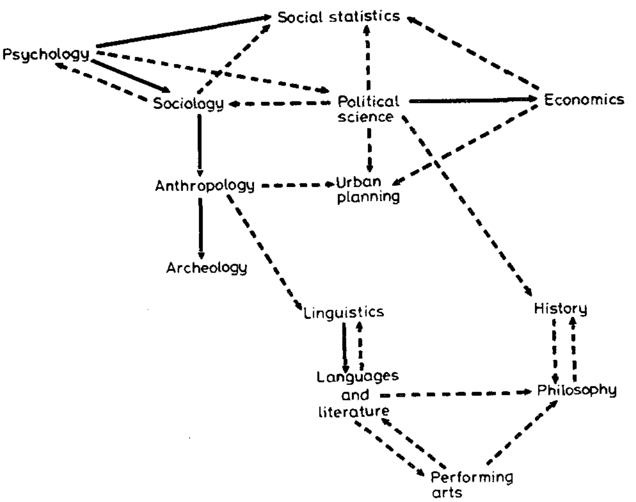

Fig. 2. Migration streams among the behavioral sciences, arts and humanities. Migration stream > 4 times predicted by QPM model ——→; Migration stream ⩽ 4 and ⩾ 2 times predicted by QPM model - - -→

The most notable feature of these results is the separation of the behavioral sciences from the arts and humanities. A boundary apparently exists between these two subgroups that is similar to, although somewhat weaker than, that in Fig. 1 between these fields as a group and the natural sciences. Disproportioinate migration flows involving history and linguistics connect fields in the two subgroups; the former linking political science and philosophy and the latter linking anthropology and languages and literature. No marked hierarchical patterns are apparent within either of the two subgroups in Fig. 2.

Figure 2 also indicates that there are disproportionate streams from the social sciences and psychology to social statistics, an area identified by the OSEP that should be considered a specialty rather than a discipline unto itself. These streams are probably best interpreted as specialization engendered by increased emphasis on quantitative techniques in the behavioral sciences.

Only *Small*'s study of cocitation clusters in the *Social Science Citation Index* is available for comparison with the migration patterns shown above, though it encompassed only the fields in the upper section of Fig. 2.[33] *Small* found that these cocitation clusters were arrayed along an individual versus group behavior dimension. The ordering of the fields in the upper section of Fig. 2 is consistent with that finding.[34] The studies of similarities among disciplines[35] identify a life system-nonlife system dimension that resembles to the distinction between individual and group behavior in *Small*'s study. Economics, English, German and Russian exemplify fields classified as focusing on nonlife systems; fields at the life- system pole include psychology, sociology, and political science and anthropology. It should be noted that the MDS analyses (see Fig. 2) placed the languages and literature group slightly closer to economics than psychology, and this is consistent with *Biglan*'s classification of English, German and Russian as nonlife system fields. On the other hand, *Biglan*'s study placed political science much closer to psychology than to economics, whereas the migration streams show the opposite result, and *Biglan*'s study placed history and philosophy in the middle of the life system-nonlife system dimension whereas the migration patterns suggest they should be placed toward the latter end of this dimension.[36] Compared to the overall similarity between the two sets of results, however, these are fairly small differences that may be due to sampling variation and differences in field coverage. In general, the results in Fig. 2 are consistent with those of the previous studies of relations among these disciplines.

Relations among the life sciences

The MDS analyses of the migration streams among the life sciences suggested that they can be represented in two dimensions. The analyses identified three groups of fields that occ:'py extreme positions the the two dimensional space: the first consists of such fields as agronomy, horticulture and forestry; the second consists of such fields as ecology, fish and wildlife sciences, and entomology; and the third of medicine and surgery, pathology and veternary medicine.[37] Figure 3 depicts the general results of these analyses and shows the major disproportionate migration streams between the fields in the life sciences.

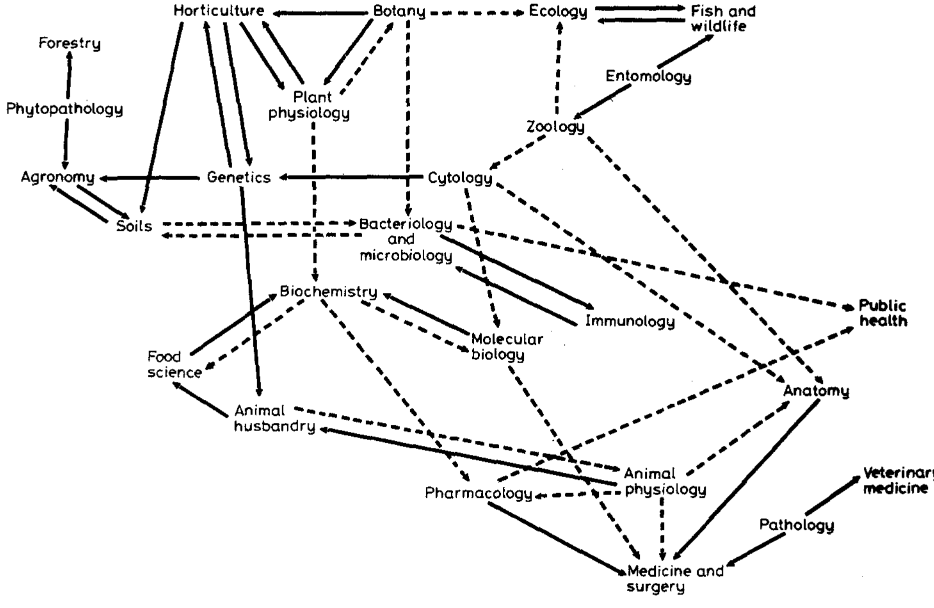

Fig. 3. Migration streams among the life sciences. Migration stream > 4 times predicted by QPM model ——→; Migration stream ⩽ 4 and ⩾ 2 times predicted by QPM model - - -→.

The first of the two dimensions in Fig. 3 distinguishes plant sciences from animal sciences, and is represented by horizontal dispersion. The second dimension appears to distinguish medical sciences from other animal sciences, and is represented by vertical dispersion on the right side of the figure. Centrally placed and about equidistant from the fields at the corners of the triangular arrangement are fields such as bacteriology and microbiology, molecular biology, and biochemistry. These fields are in the "experimental biology" category in Fig. 1, and as indicated in that figure, connect the life sciences to chemistry. Biochemistry is especially important in this respect because it is the primary field in both flows between chemistry and experimental biology.[38]

The greater coverage of fields in this study makes it difficult to compare the results in Fig. 3 with other work on the structure of these fields. *Narin,* for example, studied citation flows among "biomedical" journals that represent fields in the "medical sciences" and "experimental biology" groups in Fig. 1 and the fields in the lower central and right-hand sections of Fig. 3.[39] Using a technique for measuring the relative influence of journals in various fields, he found that biochemistry and physiology seem to be fundamental source fields for this subgroup of disciplines, and that the other fields could be arrayed in terms of whether they tended to cite either biochemical or physiological journals. He then constructed a two-dimensional representation of these fields where relative influence was one dimension and the biochemistry-physiology distinction was the second, and showed, for example, that veterinary medicine and surgery are less influential fields on the physiology end of the biochemistry-physiology dimension and that genetics and microbiology are less influential fields on the biochemistry end. The results for fields in the central and lower right sections of Fig. 3 are consistent with *Narin*'s results for the biochemistry-physiology dimension in his analysis, but the analysis of migration patterns did not produce a dimension corresponding to *Narin*'s measure of relative influence. This may be due to the fact that *Narin*'s technique for measuring relative influence forces a hierarchical ordering of fields even in cases where such an ordering is weak, or it may result from the broader coverage of life science fields in this study.

Cocitation analyses of life science papers tend to yield a single macrocluster containing many subfields. Procedures to break up this macrocluster yield a large number of quite specific research areas.[40] Thus, the results from cocitation studies seem to pertain to levels of aggregation either much grosser or finer than that summarized in Fig. 3.

Finally, although studies of disciplinary similarities classify all of the fields in Fig. 3 as "life system, hard science" fields, one might expect them to vary on the "pure-applied" dimension those studies reveal. For example, *Biglan* identified horticulture and agronomy as loading on the applied end of this dimension. In Fig. 3, however, this dimension does not seem to be present, and the spatial dispersion of fields again appears to be easily explained in terms of intellectual commonalities. *Biglan* did not study many life science fields, however, and including such fields as ecology, fish and wildlife, and veterinary medicine might have yielded a different picture of variation within this group of fields.

Intradisciplinary relations among specialties

Thus far my analyses of migration patterns have concentrated on disciplines and groups of disciplines. At this level migration patterns tend to conform to the findings from other procedures for studying the structure of scientific fields. The OSEP survey also contains information about migration patterns among specialties within four disciplines–chemistry, physics, mathematics and psychology–and it is therefore possible to study what general conclusions can be drawn about intradisciplinary migration. I used the above procedures to construct graphs of the migration streams within each of the four disciplines (see Figs 4 through 7). Although space limitations prohibit discussing each of these graphs in detail, a few general comments about them are pertinent.

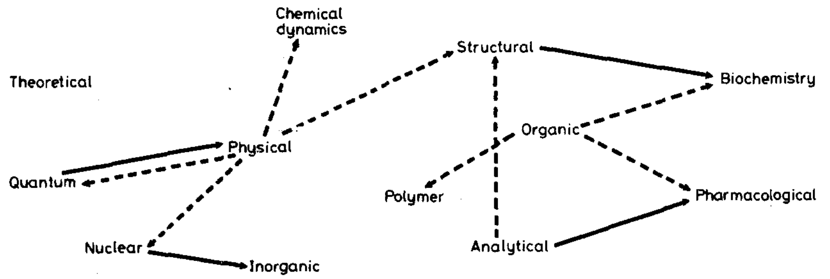

Fig. 4. Migration streams among chemistry specialties. Migration stream > 4 times predicted by QPM model ⟶; Migration stream ⩽ 4 and ⩾ 2 times predicted by QPM model - - - →

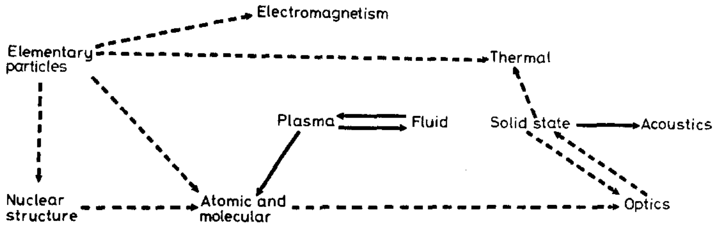

Fig. 5. Migration streams among physics specialties. Migration stream > 4 times predicted by QPM model ⟶; Migration stream ⩽ 4 and ⩾ 2 times predicted by QPM model - - - →

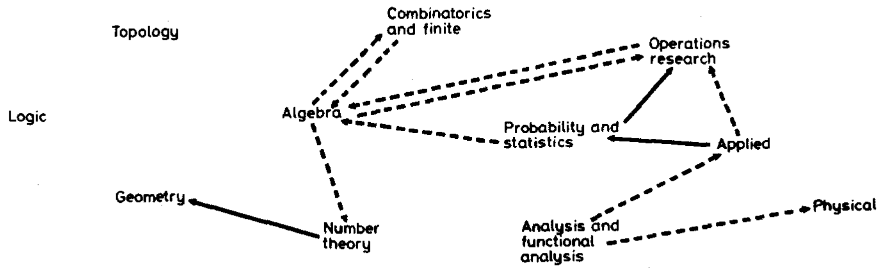

Fig. 6. Migration streams among mathematics specialties. Migration stream > 4 times predicted by QPM model ⟶; Migration stream ⩽ 4 and ⩾ 2 times predicted by QPM model - - - →

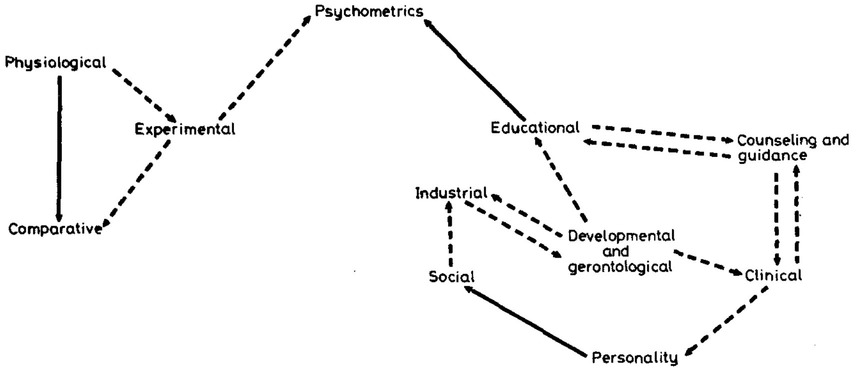

Fig. 7. Migration streams among psychology specialties. Migration stream > 4 times predicted by QPM model ——→; Migration stream ⩽ 4 and ⩾ 2 times predicted by QPM model - - -→

Since studies of citation flows or field similarities among specialties in these disciplines for comparison with my results are rare, I interviewed small numbers of researchers in each discipline about such questions as the adequacy of the list of specialties used by the OSEP survey, and their assessment of the general validity of the graphs derived from the analyses of the migration patterns.

The major migration streams among chemistry specialties shown in Fig. 4 suggest that these specialties can be arrayed along a physical-organic dimension.[41] This is, of course, consistent with chemistry's position in Fig. 1 as an intermediary between the physical and life sciences. Among the specialties on the left side of the figure, physical chemistry appears to be a dominant specialty because it is the origin of nearly all of the disproportionate migration streams between them. Organic chemistry plays a similar role among the specialties on the right side of the figure, although its dominance among those fields is weaker than physical chemistry's dominance among the fields on the left. These results are consistent with results of an analysis of journal citation flows withion chemistry reported by *Pinski.*[42] Although he did not use exactly the same specialty categories as those in Fig. 4, *Pinski* found that chemistry specialties are arrayed along a dimension from physical chemistry to biochemistry, and that physical chemistry was the most influential among all of the chemistry specialties. In contrast, however, *Pinski*'s analysis did not show organic chemistry to have an especially high level of influence among the fields on the biochemistry end of the dimension.

Figure 5 shows a similar structure for physics. Once again, the specialties exhibit a bipolar structure with elementary particle physics and nuclear structure at one end and solid state physics, acoustics and optics at the other end. Elementary particles appears to be a dominant specialty among those on the left side of the figure. My informants noted that the specialties on the right side of Fig. 5 tend to have more immediate applications to engineering problems than those on the left, but were often hesitant to interpret the horizontal dimension as consisting of a pure versus applied dimension. For example, several noted that the specialties on the left side of the figure typically deal with higher energy levels than those on the right.

Figure 6 reveals a somewhat different structure for mathematics specialties. Here specialties are arrayed along a dimension that informants interpreted as a pure versus applied dimension, but none of the specialties appear to be dominant over the others. According to my informants, boundaries between specialties in mathematics are often quite indistinct. Research can be classified as either algebra or combinatorics, for example, depending on how the researcher chooses to phrase a particular research question.[43] Thus, the lack of dominant specialties within the field may result from the often highly permeable boundaries between specialties.

Finally, Fig. 7 shows the major migration streams among specialties in psychology. These are grouped into two distinct clusters, with physiological, experimental and comparative psychology forming one and everything else except psychometrics forming the other. My informants usually identified this as a "hard-soft" dimension,[44] although some also noted that the specialties on the right side of the figure often emphasize the application of knowledge. Although physiological psychology appears to dominate over experimental and comparative psychology, no hierarchy is apparent among the specialties on the right side of the figure.

As noted above, my informants could readily interpret the horizontal dispersion of specialties in their respective disciplines as represented in Figs 4–7. In contrast, few thought the vertical dimensions of those figures were interpretable, even though the MDS analyses in each case indicated that two-dimensional representations of the migration patterns are a significant improvement over one-dimensional ones.

Conclusions

These analyses of scholars' patterns migration yield information both about methods of analyzing the structural relations among scholarly fields and about the nature of those relations in the U.S. in recent times. With regard to the first issue, the results confirm that when techniques for controlling the effects of field size are employed, one may use data on scholars' migration to study relations among scholarly fields. This is evidenced by both the consistency of results for interdisciplinary migration with previously published results based on citation-flow data and field similarities, and the interpretability of results for intradisciplinary migration.

The fields examined above are relatively large and stable, and migration data are probably less suitable for studying relations between smaller and less institution-analyzed fields of scholarship, or shorter time spans. In these cases the number of scholars who move between areas is likely to be too small to yield reliable data for determining migration patterns. For example, migration streams between major specialties in physics between 1968 and 1971 consisted of between only one and thirty scholars.[45] In general, analyses based on citation-flow data, such as cocitations, seem more suited to studying relations among small research areas over short time spans, and they have the added advantage of providing a more dynamic picture of the development of such areas through time.[46] As I pointed out above, however, this greater temporal and cognitive specificity makes it more difficult to portray relations among the broad range of larger institutionalized fields of scholarship. Citation-flow data and migration data are thus complementary in that they are suited to analyses on different levels of scientific activity.

The migration patterns shown above suggest that the primary force shaping relations among scholarly disciplines is that of cognitive commonality—the degree to which fields are concerned with similar topics and investigate them with similar concepts and methods. In contrast to results from studies of field similarities on various characteristics, differences on a pure-applied dimension do not appear to affect *inter*disciplinary migration patterns. Field relations previously interpreted as reflecting variation in consensus are reflected by the migration patterns, but in the present case at least, seem better interpreted in terms of cognitive commonality. Thus, rather than reflecting a number of distinct aspects of scholarly activity, migration patterns are sensitive primarily to a single kind of relation among disciplines.

The migration patterns also suggest that there are two significant structural boundaries among the wide range of fields included in this analysis. The first separates mathematics and the natural sciences from the behavioral sciences, arts and humanities. The second is less prominent, and separates the behavioral sciences from the arts and humanities. Migration across these boundaries is less likely than migration among the fields that the boundaries separate, and the three groups of fields therefore appear to constitute three general communities of intellectual activity.

Finally, the migration patterns do not show a clear hierarchy among the disciplines I studied. Many disproportionate flows of scholars are reciprocated, and those that are not do not form transitive chains as one would expect if even partial hierarchies were present. In contrast, hierarchical patterns are more common when one examines migration among specialties within disciplines; three of the four fields examined above show some degree of hierarchy among their specialties. *Hagstrom*'s discussion of hierarchical relations among fields[47] suggests a possible reason for this. He argues that disciplines with single unified theories, such as physics, are more likely than fields without such theories to display hierarchies of subfields because the theory makes it possible to order subfields as more or less "fundamental". The absence of hierarchical patterns among disciplines may be due to the absence of an overarching theoretical framework to integrate the activities of the various disciplines. In contrast, individual disciplines are more likely to possess such theories and are therefore more likely to exhibit hierarchies among their constituent specialties. Psychology is an interesting case in this regard because it shows a hierarchy only among the specialties on the "hard" end of its hard-soft dimension. Thus, a degree of theoretical consensus may be a precondition for the development of hierarchical patterns among scholarly fields.

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Notes and references

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2. A. COMTE, *The Positive Philosophy,* trans. by *Harriet Martineau,* New York, Calvin Blanchard, 1858, pp. 437–438; E. DURKHEIM, *The Division of Labor in Society,* trans. by *G. Simpson,* New York, Free Press, 1947, pp. 356–357.
3. T. S. KUHN, Mathematical versus experimental traditions in the development of physical science, In: T. S. KUHN, *The Essential Tension,* Chicago, Univ. of Chicago Press, 1977 p. 34.
4. A. BIGLAN, The characteristics of subject matter in different academic areas, *Journal of Applied Psychology,* 57 (1973) 195; H. G. SMALL, Cocitation in the scientific literature: A new measure of the relationship between two documents, *Journal of the American Society for Information Science,* 24 (1973) 265; F. NARIN, *Evaluative Bibliometrics: The Use of Publication and Citation Analysis in the Evaluation of Scientific Activity,* Final Report on NSF Contract C-627, Cherry Hill, N. J., Computer Horizons, Inc., 1976.
5. ARISTOTLE, *Posterior Analytics,* trans. by *J. Barnes,* London, Oxford Univ. Press, 1975.
6. W. O. HAGSTROM, op. cit., note 1, pp. 167–175. This structural definition of hierarchy is to be contrasted with non-network treatments of hierarchy as simply a rank ordering of fields on some dimension. For a discussion of this distinction, see R. L. BRIEGER, Career attributes and network structure: A biomedical research specialty, *American Sociological Review,* 41 (1976) 117. An example of the non-network approach to the concept of hierarchy is S. COLE, The hierarchy of the sciences, *American Journal of Sociology,* 89 (1983) 111.
7. H. G. SMALL, B. C. GRIFFITH, The structure of scientific literatures I: Identifying and graphing specialties, *Science Studies,* (1974) 17; B. C. Griffith, H. G. Small, J. A. Stonehill, S. DEY, The structure of scientific literatures II: Toward a macro- and microstrucutre of science, *Science Studies,* (1974) 339; F. NARIN, op. cit., note 4.
8. *Small* et al. have announced that they are currently experimenting with the combined *SCI/SSCI* files in order to produce a more inclusive map of scientific disciplines. In addition to the very large data files involved, such analyses face difficulties which stem from the fact that citation practices vary significantly between the two groups of fields (see B. C. GRIFFITH H.

G. SMALL, The structure of the social and behavioral sciences literature, *Proceedings of the First International Conference on Social Studies of Science,* Ithaca, New York, Cornell University, 1976). *Small* and *Sweeney,* and *Small* et al. discuss methods that may be able to surmount these difficulties. See H. G. SMALL, E. SWEENEY, Clustering the Science Citation Index using co-citations I: A comparison of methods, *Scientometrics,* forthcoming; H. G. SMALL, E. SWEENEY, E. GREENLEE, Clustering the Science Citation Index using co-citations II: Mapping science, *Scientometrics,* forthcoming.

9. Cocitation techniques, for example, are designed to detect areas of high activity at a given time and to study how they change through time. These areas tend to be fairly small fields of research rather than institutionalized disciplines or specialties. H. G. SMALL, B. C. GRIFFITH; B. C. GRIFFITH, et al., op. cit., note 7.
10. Studies based on citation flows implicity weight the citation patterns of prolific publishers more than the patterns of those who are less productive, and scholars who do not publish during a given period are unrepresented in such analyses. In contrast, studies of migration patterns based on samples of Ph. D. s do not involve the differential weighting of individual scholars.
11. W. C. HAGSTROM, op. cit., note 1, pp. 69–104.
12. *Van Houten* et al. show that scholars trained in physics but currently working in other fields tend to work on their own research programs and to focus on basic rather than applied questions in those fields. Furthermore, they report that the physicists are more likely to be doing research than non migrant scholars in those fields. J. VAN HOUTEN, H. G. VAN VUREN, C. LE PAIR, G. DIJKHUIS, Migration of physicists to other academic disciplines: Situation in the Netherlands, *Scientometrics,* 5 (1983) 257.
13. *Gieryn* notes that using terms such as "movement", "mobility", or "migration" are misleading insofar as they imply a disjunctive transfer of a scholar's entire commitment from one field to another. He shows that a more frequent pattern is the addition of new lines of work to an existing research repertoire. This paper reports changes of scholars' *primary* research commitments and describes them as patterns of "migration" because there seems to be no satisfactory term that encompasses *Gieryn's* objection. T. F. GIERYN, Problem retention and problem change in science, In: J. GASTON (Ed.), *The Sociology of Science: Problems, Approaches and Research,* San Francisco, Jossey Bass, 1978.
14. J. BEN-DAVID, Roles and innovations in medicine, American Journal of Sociology, 65 (1960) 557; J. BEN-DAVID, R. COLLINS, Social factors in the origins of a new science: The case of psychology, American Sociological Review, 31 (1966) 451; D. O. EDGE, M. MULKAY, *Astronomy Transformed: The Emergence of Radio Astronomy in Europe,* New York, Wiley, 1976.
15. D. URBAN, Mobility and the growth of science, *Social Studies of Science,* 12 (1982) 409. *Urban* bases his argument on results from a questionnaire that asked respondents to report the primary reason they changed university affiliations between 1974 and 1976. Nevertheless, *Urban* seems to exaggerate the extent to which job opportunities are *independent* of cognitive changes within science; cognitive migration may be due to intellectual developments within science even though individual migrants attribute their movements to job opportunities. It should also be noted that a substantial proportion of *Urban's* respondents, 35 percent, were graduate students.
16. E. NOMA, An improved method for analyzing square scientometric transaction matrices, *Scientometrics,* 4 (1982) 297.
17. Office of Scientific and Engineering Personnel, National Research Council, *Science, Engineering and Humanities Doctorates in the United States: 1981 Profile,* Washington, D. C., National Academy of Sciences, 1982, pp. 101–112.
18. These settings include business and industry, junior colleges, elementary and secondary schools, clinics and hospitals not part of medical schools, the military, and positions with local

governments. See the complete list of organizational settings in Office of Scientific and Engineering Personnel, op. cit., note 17.

19. See Office of Scientific and Engineering Personnel, op. cit., note 17, pp. 68–72 for a reproduction of the survey questionnaire and specialty list. Most of these "specialties" correspond to what are normally called disciplines, such as genetics, anatomy, sociology and philosophy. In some cases, however, large disciplines are broken down into major subfields. For example, within chemistry analytical, inorganic, physical, etc. are distinguished. Below I focus on interdisciplinary migration patterns first and then briefly examine migration within each of the four large disciplines for which data on intradisciplinary migration are available.

20. For an overview of the general types, see R. S. BURT, Models of network structure, *Annual Reviews of Sociology*, 6 (1980) 79.

21. P. M. BLAU, O. D. DUNCAN, *The American Occupational Structure*, New York, Wiley, 1967.

22. L. A. GOODMAN, On the statistical analysis of mobility tables, *American Journal of Sociology*, 70 (1965) 564.

23. I used most of the general categories from the OSEP list for my analysis with a few exceptions. First, I split the "physics and astronomy" category into astronomy and astrophysics on the one hand and the remaining physics specialties on the other. Similarly, I broke the "earth, environmental and marine sciences" category into atmospheric sciences and geological sciences, with the latter including oceanography and other marine sciences. Following a distinction made by *Hagstrom*, I separated the OSEP's general "biological sciences" category into two subcategories: experimental biology and other biology. The former includes such fields as biochemistry, molecular biology and physiology, and the latter such fields as botany, ecology and zoology. W. O. HAGSTROM, Competition in science, *American Sociological Review*, 39 (1974) 1. The OSEP also included "biomathematics", "biostatistics" and "biometrics" in the biological sciences category, but since these fields seem distinct from the others in the category, I retained them as a separate group of fields, labeled biostatistics, for my analysis. The OSEP's "chemistry" category contained biochemistry as a specialty, but I combined it with the biochemistry category within the experimental biology category discussed above. I also combined the "humanities" and "languages and literature" categories from OSEP's list into a broader arts and humanities category for my analysis. However, I combined four history subcategories from the humanities category into a general history category. Finally, I excluded a number of professional fields from my study. These include such fields as law, social work, education, journalism, business administration, nursing and hospital administration.

24. Frequencies in cells on the main diagonal represent individuals who are currently working in the same areas as their doctorates and are therefore not included in this analysis of migrants. Due to space limitations, I do not report the crosstabulation table upon which my analysis is based. Interested readers may obtain any of the tables in the analysis reported here from the author.

25. Specifically, Kruskal's stress coefficient equalled 0.31, 0.11 and 0.07, respectively, for the 1, 2 and 3 dimensional solutions when field inflow patterns were analyzed. The corresponding values for the analysis of field outflow patterns were 0.39, 0.17 and 0.09.

26. For a summary of this last of work see J. C. SMART, C. F. ELTON, Validation of the Biglan model, *Research in Higher Education*, 17 (1982) 213. In addition to the work using citation flows and field similarities, there has been a little work on the "migration" of U. S. college students among fields. See J. L. SPAETH, Patterns of change in the long-run career fields of June, 1961 college graduates, *Proceedings of the Social Statistics Section of the American Statistical Association*, 8 (1965), 81. *Spaeth*'s results are for highly aggregated groups of fields, but parallel those of this study in showing that the natural sciences are ordered from the physical sciences to medicine, and that there is little migration between (1) the natural sciences and (2) the behavioral sciences, arts and humanities.

27. B. C. GRIFFITH et al., op. cit., note 7.
28. F. NARIN, M. CARPENTER, N. C. BERLT, Interrelations of scientific journals, *Journal of the American Society for Information Science*, 23 (1972) 323.
29. J. C. SMART, C. F. ELTON, op. cit., note 26.
30. A. BIGLAN, op. cit., note 4.
31. The Kruskal stress coefficient equalled 0.28, 0.16 and 0.10, respectively, for 1, 2 and 3 dimensional solutions for analyses of field inflow patterns. The corresponding values for field outflow patterns were 0.24, 0.14 and 0.09.
32. Some of the social sciences and humanities "specialties" on the OSEP list had to be dropped from this analysis. For example, "social sciences, general and other" and "humanities, general and other" were dropped because they are nonspecific residual categories. In addition, four fields on the OSEP list had to be dropped because the survey found that they either sent no Ph. D. s to the other fields in this analysis or received no Ph. D. s from them. These include geography, communications, area studies and criminology, Finally, I combined some of the fields on the OSEP list ot create a "performing arts" category and a "languages and literature" category. The former consists of theater, music, speech and art, and the latter includes such fields as English, German, Russian, etc. The individual fields within these two categories are often small, and they tend to have similar inflow and outflow patterns as the other fields in their category.
33. *Small's* results are reported in E. GARFIELD, *Citation Indexing: Its Theory and Application in Science, Technology and the Humanities,* New York, Wiley, 1979, pp. 137–140.
34. The units in Fig. 2 are disciplines, however, while those in *Small's* analysis are clusters of highly cocited papers. Thus, "linguistics" in *Small*'s analysis is not equivalent to the *discipline* of linguistics that is present in Fig. 2.
35. A. BIGLAN, op. cit., note 4. J. C. SMART, C. F. ELTON, op. cit., note 26.
36. All of the fields contained in *Biglan's* study and Fig. 2 would be classified by*Biglan* as "soft" and "pure" fields. Thus, *Biglan* identified only one dimension as differentiating the fields in Fig. 2, the life system- nonlife system dimension.
37. The Kruskal stress coefficient equalled 0.35, 0.17 and 0.12, respectively, for the 1, 2 and 3 dimensional solutions for analyses of field inflow patterns. The corresponding values for the field outflow patterns were 0.29, 0.16 and 0.12. Once again, I dropped nonspecific residual categories, such as "agricultural sciences, general and other", from the analysis. I also had to drop "animal science", "hydrobiology", "behavior/ethology" and "nutrition and dietetics" from the analysis because they either sent or received no one to the other fields. Finally, I combined the categories of "pharmacy" and "pharmacology" into a single general category denoted as "pharmacology" in this analysis, and "biochemistry" and "biophysics" into a general biochemistry category.
38. Biochemists make up 96 percent of those who moved from experimental biology to chemistry, and 91 percent of those who moved from chemistry to experimental biology are biochemists.
39. F. NARIN, op. cit., note 4.
40. E. GARFIELD, op. cit., note 33, pp. 111–118.
41. In order to enhance the comparability of this study with that of *Pinski* (op. cit., note 42), biochemists are included in this analysis of chemistry specialties. The reader will recall that biochemists were also included in the analysis of migration among the life sciences.
42. G. PINSKI, Influence and interrelationship of chemical journals, *Journal of Chemical Information and Computer Science,* 17 (1977) 67.
43. The indistinct boundaries between mathematical specialties is also reflected by the many intermediate subcategories in the subject classifications used by *Mathematical Reviews.* See, for example, the Subject Index in *Mathematical Reviews: 1984 Annual Index,* S1-S40.
44. See also G. A. KIMBLE, Psychology's two cultures, *American Psychologist,* 39 (1984) 833.

45. Physics Survey Committee, National Research Council, *Physics in Perspective,* Vol. 1, Washington, D. C.: National Academy of Sciences, 1972.
46. See H. G. SMALL, A co-citation model of a scientific specialty: A longitudinal study of collagen research, *Social Studies of Science,* 7 (1977) 139.
47. W. O. HAGSTROM, op. cit., note 1, pp. 168–170.