miscellaneous (technical report, computer program, lab manual, specifications, kit, test, CD-ROM database), unpublished paper (manuscript, in press), thesis, serial, and reference book. Of those cited references, 82 percent were to journal articles, 8 percent to books, 5 percent to conference papers, 2 percent to monographic series, and 1 percent each to miscellaneous and unpublished. Other publication types each were less than one percent. NACS members included in this study cited journal articles at a lower rate than the molecular biologists in Hurd's study (83% compared to 93%), but cited books (8% compared to 4%) and conference papers (5% compared to 0.4%) at a higher rate.

Neurosciences was the most commonly occurring subject category (26%) for the cited articles. (See table 4.) NACS authors

TABLE 3
Ranking of ISI Subjects by Count of Articles (n = 170)

ISI Subject Category	No. of Articles	ISI Subject Category	No. of Articles
Neurosciences	69	Neuroimaging	3
Acoustics	18	Psychology, Educational	3
Applied Linguistics	14	Cell Biology	3
Behavioral Sciences	12	Communication	2
Psychology	11	Computer Science, Interdisciplinary Applications	2
Endocrinology & Metabolism	9		
Physiology	8	Biology	2
Zoology	7	Psychology, Mathematical	2
Computer Science, Artificial Intelligence	7	Genetics & Heredity	2
		Geriatrics & Gerontology	2
Otorhinolaryngology	6	Mathematics, Interdisciplinary Applications	2
Ophthalmology	5		
Psychology, Applied	5	Nutrition & Dietetics	2
Psychology, Experimental	5	Pediatrics	2
Agriculture, Dairy & Animal Science	4	Engineering, Biomedical	2
		Robotics	2
Clinical Neurology	3	Toxicology	1
Engineering, Electrical & Electronic	3	Telecommunications	1
		Radiology, Nuclear Medicine & Medical Imaging	1
Education, Special	3		
Developmental Biology	3	Public, Environmental & Occupational Health	1
Computer Science, Cybernetics	3		
Sport Sciences	3	Multidisciplinary Sciences	1
Psychology, Developmental	3	Psychology, Multidisciplinary	1
Psychiatry	3	Environmental Sciences	1
Biophysics	3	Psychology, Social	1
Biochemistry & Molecular Biology	3		

cited the literature that was classed as zoology and physiology, both subsets of biological sciences, six percent of the time each, and psychology, multidisciplinary sciences, and behavioral sciences, each five percent of the time. ISI subjects used less than one percent of the time are not included in table 4.

Table 5 shows the ranked order of journals cited. Only journals with fifty or more cites are displayed. For the most popular journal, *Journal of the Acoustical Society of America*, a parallel trend emerges between publication and citation data. Although this journal ranks highest among journals in which NACS authors published and also among those they cited, the subject category of acoustics ranks far below neurosciences. Out of the 170 NACS articles analyzed, 41 percent were classed in neurosciences (table 2) and 26 percent of the journals cited were classed in neurosciences (table 4). Only about 10 percent of published NACS articles (table 3) and 4 percent of journals cited (table 5) were classed in acoustics. The fact that many journals have a secondary subject of neurosciences may have contributed to this result.

TABLE 4
Ranked Order of Subject Categories of Cited References (journals only) (n = 9,284 ISI subject occurrences in 6,270 cited journal references)

ISI Subject Category	No. of Journal Cited References	Percentage of ISI Subject Category
Neurosciences	2385	26%
Zoology	563	6%
Physiology	541	6%
Psychology	454	5%
Multidisciplinary Sciences	448	5%
Behavioral Sciences	434	5%
Acoustics	397	4%
Endocrinology & Metabolism	317	3%
Applied Linguistics	305	3%
Psychology, Developmental	265	3%
Biochemistry & Molecular Biology	247	3%
Otorhinolaryngology	234	3%
Psychology, Educational	215	2%
Clinical Neurology	166	2%
Cell Biology	135	1%
Psychology, Experimental	125	1%
Biology	122	1%
Developmental Biology	120	1%
Psychiatry	105	1%
Ophthalmology	102	1%

A comparison of tables 2 and 5 shows that of the top ten journals in which NACS authors published and cited from 2001 to 2003, five titles were the same. Again, *Journal of the Acoustical Society of America* occupies the top spot in both the publications and citations of NACS authors. Other journals appearing in both the top ten published in and cited journals are *Journal of Neurophysiology*, *Journal of Comparative Neurology*, *Hearing Research*, and *Brain Research*. Note that the multidisciplinary nature of the field precludes any one journal from dominating as a source of citations. The highest-ranked journal, *Journal of the Acoustical Society of America*, has only six percent of the total citations. Note also that the three general science journals in table 5 (*Science*, *Nature*, and *Proceedings of the National Academy of Sciences*) are the three that Carolyn Virginia Mills identified in 1993 as the most important general science journals in molecular and cellular neurosciences.[21]

Time Interval between Published Articles and Cited References for Journals

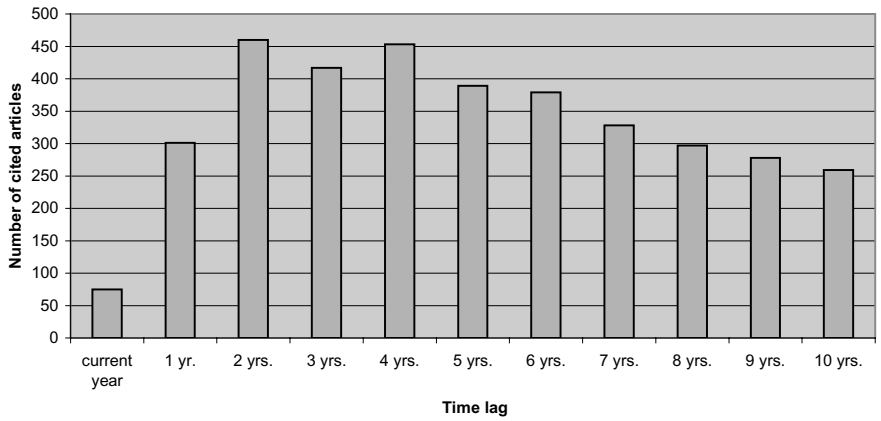
The authors calculated the time interval between each NACS published article and each of its journal references. Out of the total 6,270 citations, the largest number (3,635) was to materials up to ten years old. (See figure 1.)

Unlike Hurd, Blecic, and Vishwanatham's finding that molecular biologists tend to cite recent journal literature (58% of cited material was five years old or less at time of publication of the citing article), this study's finding is that NACS authors cite more of the older literature. Only 33 percent of cited material in this study was five years old or less, and 54 percent of the cited material was nine years old or less. Compared to molecular biologists, neuroscientists are more likely to build on older work. In fact, almost 30 percent of all material cited (1,825 citations) was to articles fifteen years or older, and 8 out of 6,269 citations were to publications 90 to 107 years old. The variability of publication lag in different disciplines has been noted in previous studies.[22] That neuroscientists cite much older literature than molecular biologists is not surprising because the study of the brain predates the discovery of DNA by centuries. Alcmaeon, student of Pythagoras, conceived the brain rather than the heart as the seat of intellect as early as the sixth century B.C., and this has been irrefutable since the nineteenth century.[23] The findings of this study also corroborate the work of E. J. Rinia et al., who found that citation time interval varies by discipline and the degree to which the field of study is multidisciplinary. They found that the time interval between articles and their references is shorter for individual disciplines than for fields that are more multidisciplinary, at least in the life sciences, computer sciences, materials sciences, and pharmacology. Given the multidisciplinary nature of neuroscience, it is not surprising that neuroscience research has longer time intervals than

TABLE 5
Ranked Order of Journals Cited by NACS Authors (N = 6,270 Citations to 786 Journals)

Journal Name	No. of Journal Citations
Journal of The Acoustical Society of America	348 (6%)
Journal of Comparative Neurology	297 (5%)
Journal of Neuroscience	270 (4%)
Journal of Neurophysiology	195 (3%)
Science	155 (35%)
Hearing Research	145 (2%)
Nature	127 (2%)
Brain Research	117 (2%)
Proceedings of the National Academy of Sciences of the United States of America	112 (2%)
Child Development	99 (2%)
Journal of Comparative Physiology A-neuroethology Sensory Neural and Behavioral Physiology	88 (1%)
Experimental Brain Research	88 (1%)
Electroencephalography & Clinical Neurophysiology	77 (1%)
Endocrinology	75 (1%)
Journal of Speech Language and Hearing Research	68 (1%)
Psychophysiology	65 (1%)
General and Comparative Endocrinology	57 (1%)
Vision Research	57 (1%)
Neuron	52 (1%)
Brain Behavior and Evolution	50 (1%)
Developmental Psychology	50 (1%)

FIGURE 1
Time Lag Between Publication of Articles and Publication of Cited References First 10 Years



research within a single discipline such as molecular biology.[24]

Coauthorship Patterns of NACS authors

Previous studies have noted a systematic increase in collaboration on scholarly publications, although the extent to which researchers collaborate in their work and coauthor publications varies markedly by discipline.[25] In general, researchers in the sciences collaborate more than in the social sciences, and even more so than in the humanities. Even within the sciences, however, studies such as that of M. E. J. Newman have shown variations in the average number of collaborators per published document. Newman found that biologists have four times as many collaborators as mathematicians.[26]

This study afforded the opportunity to investigate patterns of coauthorship among neuroscientists. The NACS community holds weekly colloquia in which NACS members and invited outside speakers share research related to neuroscience and cognitive science. Thus, many opportunities exist to exchange ideas. The authors of this study were interested in the degree to which NACS members took the opportunity to initiate research with each other and especially to cross departmental lines in the process.

Specifically, the authors asked four questions. First, because NACS membership represents departments that are classed as sciences, social sciences, as well as humanities, do researchers in this program follow the science pattern of frequent copublishing? The authors hypothesized that the experimental and multidisciplinary nature of the discipline would favor multiple authorship. The findings were that, indeed, a great deal of coauthorship occurred. Only 11 of 170 (6%) NACS articles had single authorship, with no pattern favoring any particular discipline. NACS researchers follow the science pattern of a high degree of coauthoring.

Second, the authors were interested in the degree to which NACS members coauthor with faculty on the Maryland campus. Traditionally, coauthorship has been assumed to be a function of proximity; the closer geographically researchers are to each other, the likelier they are to coauthor. However, M. Sutter and M. Kocher discovered that in the field of economics, distance and other geographical variables are no longer predictors of collaboration.[27] It appears that the ease

of electronic communication widens the pool of colleagues and greatly facilitates long-distance coauthorship. Thus, the question for the authors of this study was whether local neuroscience coauthoring patterns would conform to traditional proximity patterns. The authors hypothesized that proximity and ease of contact would facilitate campus-internal coauthoring. Complex coauthoring patterns were found, with many articles authored by both campus and outside researchers. Articles with any Maryland coauthors were compared with those in which the NACS researcher coauthored exclusively with outside researchers. The results favored campus-internal coauthoring behavior, but given that articles written by both campus and outside coauthors were grouped with the campus researchers, the trend was not very strong: campus-internal coauthoring was 62 percent, and exclusively outside coauthoring was 38 percent. (See table 6.)

TABLE 6
Collaboration on NACS Coauthored Journal Articles (n = 159)

Any UMCP collaboration	98 (62%)
NACS only	10 (10%)
Non-NACS only	70 (71%)
NACS & Non-NACS	18 (19%)
Non-UMCP	61 (38%)

Third, the authors were most interested in finding out whether campus-internal coauthoring among NACS researchers was primarily with each other or with non-NACS researchers. Specifically, does shared membership in NACS and the sharing of research via colloquia foster a high degree of coauthoring? The patterns of NACS-internal coauthoring were complex. Three sets of coauthorship patterns were compared: (1) coauthoring exclusively with other NACS researchers; (2) coauthoring exclusively with UMCP colleagues who are not NACS members; and (3) coauthoring with both NACS members and UMCP non-NACS colleagues. (See table 6.) The results were surprising. NACS-only research accounted for only 10 percent, and NACS and non-NACS coauthorship accounted for 19 percent of the total University of Maryland coauthoring pattern. Thus, *any* NACS coauthoring only accounted for 29 percent of campus-internal coauthoring. NACS researchers coauthored with non-NACS researchers more than twice as often (71% of the time) as they did with fellow NACS members.

Finally, the authors wanted to know whether the NACS connection afforded more opportunity for interdepartmental cooperation than might otherwise be expected. The authors hypothesized that the NACS program would facilitate coauthoring opportunities between different departments. Even though NACS-internal coauthoring was less than anticipated, the authors were still interested in the extent to which coauthoring was not within a researcher's own department. The basis of comparison was *any* campus-internal NACS coauthoring with *any* campus-internal non-NACS coauthoring. Of the 28 instances of NACS coauthoring, 8 (29%) included researchers from other departments, whereas only 13 of 88 instances (15%) of non-NACS coauthoring included researchers from other departments. Though the numbers were not large, NACS researchers coauthored across departments about twice as often as non-NACS researchers. The hypothesis that membership in this multidisciplinary program fosters interdepartmental coauthoring was supported.

Conclusions and Directions for Future Research

During 2001–2003, NACS research at the University of Maryland was multidisciplinary. NACS authors' citing behavior crossed disciplinary lines to include the biological sciences, general and multidisciplinary sciences, and psychology and behavioral sciences. The ISI subject "neurosciences" constituted the highest

number of both publications and cited references for NACS authors in this study. They primarily cited journal articles, with other materials such as books and conference publications ranking second and third, respectively. The authors identified a set of journals classed neurosciences in which NACS authors published and cited, respectively, in order to inform selection decisions. Those journal titles are presented in table 2 and 6 in ranked order.

Compared to the population of molecular biologists that Hurd et al. studied, NACS authors relied more on older literature. Nearly one-third of the material cited by NACS authors was fifteen years or older, and only one-third of the material cited by NACS authors was five years old or less. Future investigations could address the effect of exclusive use of online journals on neuroscientists' research.

Coauthorship patterns can reveal the degree to which a field is interdisciplinary. NACS researchers showed a high degree of co-authoring. The discovery that neuroscientists primarily submit coauthored research for publication follows the pattern of substantial collaboration in the sciences and increased collaboration in general. Although electronic communication allows a greater degree of long-distance coauthoring opportunities than in the past, UMCP neuroscientists still coauthor primarily with researchers on their own campus. This is reasonable because much of the experimental research reflects the use of highly specialized equipment and is associated with particular labs. However, it is not clear why they coauthored with departmental colleagues more than with fellow NACS members. The NACS-specific patterns may be suggestive of any multidisciplinary group: while the group-internal coauthoring might be less than hoped for, one can still see an influence of the group in an increased amount of interdepartmental coauthoring.

It would be difficult for librarians at other institutions that offer neuroscience programs to use the data from this study unless graduate programs at their institutions are structured similarly to those at the University of Maryland. Graduate programs in neuroscience and neurobiology exhibit wide variability in structure and disciplinary focus, thus making it difficult to apply this study's findings directly to other institutional settings.[28] However, the citation analysis methodology used in this study provides a model for librarians to identify the literature used by cross-departmental graduate programs in the neurosciences or other interdisciplinary fields. Although the primary methodology for this study was citation analysis, a more thorough investigation using coauthorship or collaboration patterns can be employed to fully explore the nature and degree of interdisciplinary work in neuroscience research in general, or within a particular area in it. Future investigators also may wish to broaden the scope of this case study to identify a more representative sample of the neuroscientist population than the NACS group at the University of Maryland.

Notes

1. Available online at http://www.umd.edu/NACS/.
2. Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell, *Principles of Neural Science*, 4th ed. (New York: McGraw-Hill, Health Professions Division, 2000), 5.
3. *Brain Facts: A Primer on the Brain and Nervous System*, 4th ed. (Washington, D.C.: The Society for Neuroscience, 2000). Available online at http://web.sfn.org.
4. Society for Neuroscience (SfN) Web site: http://web.sfn.org.
5. The terms "multidisciplinary," "interdisciplinary," and "cross-disciplinary" are used inconsistently and somewhat interchangeably in the literature. For this study, the authors described neuroscience at the University of Maryland as "multidisciplinary," meaning that it involves more

than two disciplines.

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8. Steve Black, "Using Citation Analysis to Pursue a Core Collection of Journals for Communication Disorders," *Library Resources & Technical Service* 45 (Jan. 2001): 3–9.

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10. Paul Kelsey and Tom Diamond, "Establishing a Core List of Journals for Forestry: A Citation Analysis from Faculty at Southern Universities," *College & Research Libraries* 64 (Sept. 2003): 357–77.

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23. Larry W. Swanson, *Brain Architecture: Understanding the Basic Plan* (Oxford: Oxford University Pr., 2003), 7.

24. E. J. Rinia, T. N. van Leeuwen, E. E. W. Bruins, et al., "Citation Delay in Interdisciplinary Knowledge Exchange," *Scientometrics* 51 (May 2001): 293–309.

25. Liu, "Trends in Transforming Scholarly Communication and Their Implications."

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28. *Peterson's Graduate Programs in the Biological Sciences*, 38th ed. (Princeton, N.J.: Thomson Peterson's, 2004).