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# Cognitive Science: Interdisciplinarity Now and Then

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# Cognitive Science: Interdisciplinarity Now and Then

## Introduction

Cognitive science is a relatively young field. Its beginnings are typically dated in the 1950s, and it did not become a large-scale activity (with a society, meetings, and degree programs) until the late 1970s or early 1980s. As in most young fields, one of the salient features of cognitive science is its interdisciplinarity. All definitions of cognitive science make important mention of this feature, although they may vary slightly in which disciplines they include as contributing to cognitive science (e.g., Collins, 1977; Hardcastle, 1996; Simon, 1982; Simon & Kaplan, 1989; Van Eckardt, 2001).

Why did researchers from several different disciplines come together to form cognitive science? More generally, why do researchers from different disciplines ever come together to form new disciplines? The institutional and disciplinary barriers to interdisciplinary work can be quite formidable. The goal of this chapter will be to examine this general question using the case of cognitive science.

To examine this question, we will use a historical analysis methodology. In particular, we will analyze the state of interdisciplinarity in cognitive science, both historically and recently. Two questions will be at the forefront of our investigation. First, which disciplines have taken part in cognitive science? Second, what factors account for the relative presence or absence of each discipline in cognitive science? It is our belief that understanding how and why members of existing disciplines take part in the formation of another will provide an important insight into the process by which new disciplines are formed.

In studying the field of cognitive science, we use a case study approach. In particular, we focus on the Cognitive Science Society, an influential force in the field. The Society has two main social worlds: its production world, the journal Cognitive Science, and its communal world, the Annual Meeting of the Cognitive Science Society. At the end of the chapter, we will briefly consider data from sources outside of the Society.

This chapter extends similar data analyses found in Schunn, Crowley, and Okada (1998). The earlier paper should be consulted for more detailed analyses of the functionality of collaborations. On the topic of the interdisciplinarity of cognitive science, this chapter goes beyond the earlier paper both in the kinds of analyses conducted and the scope of the data sets analyzed.

## The Journal Cognitive Science

### Background

Cognitive Science is a high quality journal that has citation impact levels among the upper tiers of social science journals. The journal was first published in 1977. At that time, its subtitle was: "A multidisciplinary journal of artificial intelligence, psychology, and language." Thus, we see early evidence of both interdisciplinarity and focus on a particular set of disciplines.

In 1980, it was given to the Cognitive Science Society to become the Society's official journal. Since then, all members receive a subscription as part of their membership dues. In 1984, Cognitive Science merged with the journal Cognition and Brain Theory. For several years thereafter, the journal's subtitle was "Incorporating Cognition and Brain Theory." Cognition and Brain Theory had a stronger focus on neuroscience and philosophy (Waltz, 1985; Ringle &

Arbib, 1984). Therefore, we see an apparent growth of Cognitive Science to include these other disciplines as well.

In 1988, reflecting this growth in disciplines, the journal subtitle became "A multidisciplinary journal incorporating artificial intelligence, linguistics, neuroscience, philosophy, psychology." Of particular note, the order of the disciplines is now alphabetical, reflecting a desire for equal contributions from each of the disciplines. In 1997, the journal subtitle added anthropology and education to the subtitle list of disciplines. The alphabetic ordering was maintained.

The journal has typically been published quarterly, with 3-5 articles per issue; in 2001, it moved to bimonthly. The small number of articles in each issue allows for longer articles. These longer articles facilitate presentation of interdisciplinary work because multiple methodologies often require extra space to be adequately described, especially to members of the other disciplines.

## But how interdisciplinary is it really?

The descriptions of the journal suggest that the journal should be quite interdisciplinary. However, official descriptions and actual content are not always the same. With the goal of examining how interdisciplinary the journal actually is, we examine three aspects of the journal. First, we will examine the participation of each discipline with an analysis of departmental affiliations of article authors. Second, we will examine the reliance on past work from each discipline with an analysis of references found in articles. Third, we will examine the use of methodologies taken from each discipline with an analysis of the primary methods used in each article. To examine the evolution of these measures throughout the history of the journal, we compared articles published in the first five years of the journal (1977–1981), articles published

in the mid 1980s (1984–1988), articles published in the early 1990s (1991–1995), articles published in the late 1990s (1996-1997), and articles published in early 2000s (2002). Inter-rater agreement for all coding exceeded 90%.

Department Affiliations

One measure of disciplinary membership is departmental affiliation. To examine disciplinary participation in the journal, we coded the departmental affiliations of the first authors of all articles, excluding editorials, commentaries, and special issues. Only first authors are included because Cognitive Science formatting lists the department affiliations of only the first author. We code all such articles in each of the time periods.

Figure 1 presents the percent of affiliations in each of the categories in each of the time periods. From this figure, it is clear that the journal has always been dominated heavily by psychologists and computer scientists. At its inception, the journal had a near majority of computer scientists (41%), whereas this has shifted to a majority of psychologists (64%) more recently. Of particular note is the minimal participation of philosophers, linguists, and neuroscientists (means each less than 5%). Turning to the latest additions to the journal (education and anthropology): there have always been some authors from Schools of Education publishing in the journal, although the levels have never been very high (<7%). There has also been no increase since the change in the subtitle. If the affiliations are accurate, no author from Anthropology department has yet been published in Cognitive Science.

It is likely that the drop in number of computer scientists is due to the formation of the American Association for Artificial Intelligence in the early 1980s. It is unclear whether the recent drop in number of researchers with Cognitive Science affiliations is a real effect or simply noise due to the smaller number of articles included in the most recent time period.

It is worth noting that first author affiliations can be misleading, especially in the case of interdisciplinary work. Computer scientists or anthropologists can hold positions in psychology departments, for example. Moreover, even when training degrees match departmental affiliations, some of the people could hold undergraduate or masters in other fields. Finally, since the journal only listed first author departmental affiliation, it is possible that the other disciplines participated more heavily in lower status author positions. For all of these reasons, it is important to look beyond just listed affiliations.

Citation of Disciplinary Work

Another measure of interdisciplinary activity is the extent to which new work builds upon previous work in other disciplines. One measure of reliance on previous work is the frequency of citations. We see citations rates as approximate measures of a discipline's impact on cognitive science articles. Clearly, it is possible for a single seminal article to have a greater intellectual impact on a research project than, for example, any 10 other citations from the reference list combined. However, in the absence of any better way to assess the relative impact of previous research, the overall proportion of references to each discipline serves as a functional estimate of how influential various disciplines have been, in aggregate, on the work published in Cognitive Science.

For each article, we coded every reference for the discipline it represented: psychology, artificial intelligence, linguistics, neuroscience, philosophy, education, cognitive science, or other. As the reference coding involved significant labor, we coded references from three years within each of the three large time periods (i.e., 9 years total). These were selected by taking the first, middle and last year within each five-year age range, producing 5349 coded references.

The disciplines of journal articles were coded using the classifications in Ulrich's international periodical directory. The disciplines of conferences were coded according to the name of the conference. The disciplines of technical reports were coded according to the department publishing the report. It proved much more difficult to find external validation for coding books and book chapters. They were coded according to a best guess of their content. When a book or book chapter was too ambiguous to code, coders were instructed to exclude that item. This occurred for 39% of book references. The three most common reasons that references were not coded were non-English titles, very short book titles, and missing departmental affiliations from references to dissertations and technical reports. While the dropout rate for books and book chapters is quite high, it is important to note that when the data were analyzed excluding all books and book chapters, the overall pattern of results did not change. Moreover, careful investigation of a subset of these ambiguous references suggested that there were not large differences in the proportion of references to each discipline between the non-ambiguous and ambiguous references.

Figure 2 presents the mean percentage of citations to each discipline within each of the time periods. The overall pattern is similar to what was found with analyses of affiliations. First, just as with the affiliation data, there is a dominance of psychology and computer science (means of 37% and 25%), beginning with more computer science and ending with more psychology. However, there is one important difference from the affiliation analyses: linguistics was cited more frequently (mean of 12%) than linguists took part in the journal as first authors (mean of 2%). Thus, it appears that linguistics is considered relevant to Cognitive Science by other cognitive scientists. We will return to possible causes of this asymmetry in participation and apparent relevance later. It appears, however, that there is no asymmetry for philosophy,

neuroscience, anthropology, and education: Not only do researchers from those disciplines not publish in Cognitive Science, it appears that research from those disciplines is not typically cited either (means all below 3%).

Methodologies

A third measure of interdisciplinarity of the journal involves the methodologies of the work reported in the journal articles. Since the previous analyses revealed that the journal is dominated by psychology and computer science related work, one could reasonably focus on the primary methodologies from those two disciplines: empirical studies of behavior and computer simulation. We originally coded each article from the '77–'81, '84–'88, and '91–'95 periods into one of five categories: simulation only; empirical study only; simulation+empirical study; simulation of data; or neither simulation or empirical study. The simulation of data category was used for articles presenting simulations of empirical data sets that had been presented elsewhere.

These analyses found that just under one third of the articles published in Cognitive Science used empirical studies and one quarter used simulations only. Thus, at least half of the work in the journal reflects within discipline activity, and those disciplines are computer science and psychology. However, a sixth of the articles involved either empirical+simulation studies or simulations of data, suggesting that there is some integration of psychological and computer science activities within cognitive science.

The remaining one third of the articles presented neither simulations nor empirical studies. What kind of research did these articles represent? Is it possible that here a strong philosophical or linguistic presence could be seen? To investigate this issue, we coded all articles in the 1996 and 1997 issues of the journal Cognitive Science using finer coding categories. The categories and the percentage of articles coded into each category were: psychological empirical

34%, running simulations 34%, linguistic analyses 0%, philosophical argumentation 3%, neurological data involving brain damaged patients or brain imaging data 0%, new theory/frameworks 7%, combinations 17%, and other 3%. All but one of the combinations involved psychological empirical and simulations—the remaining combination involved linguistic analysis and running simulation. Analyses of methodologies in 2002 articles finds a similar trend but a larger proportion of psychological empirical. Thus, it appears that psychological and computational methodologies remain the dominant forces within the journal—philosophical argumentation, linguistic analyses, and neurological data can only be found in very small quantities.

Summary of findings

From the analyses of departmental affiliations, discipline citations, and research methodologies, a consistent picture of the journal Cognitive Science has emerged: it is dominated by psychology and computer science. The other disciplines thought to belong to cognitive science—linguistics, philosophy and neuroscience—appear to be unequal partners in the journal. Interestingly, cognitive science as a discipline of its own with its own communal and production worlds is becoming increasingly more common in the journal. We now turn to examining the communal world associated with the Cognitive Science Society: its annual meeting.

## The Annual Meeting of the Cognitive Science Society

Background

The Annual Meeting was first convened in 1979. In 1983, it became peer reviewed. The reviewing selection criteria have become stricter each year since then. In the past several years,

approximately 40% of submitted papers are accepted. Over the years, the conference has also grown steadily in size, until it stabilized in the early 1990s at approximately 140 papers and posters and 500 attendees. In the middle 1990s, a category of member abstracts was added, in which any member of the society could have a poster and a one page abstract in the proceedings without having to go through the review process. While the analyses presented below do not include data from member abstract posters, the results do not change noticeably when they are included.

Motivation for examining the conference

There are three reasons that one might expect to see a different picture of cognitive science when examining the Annual Meeting. First, the journal Cognitive Science is highly selective. Yet, interdisciplinary work tends to be more novel and speculative in nature. Therefore, it is possible that much interdisciplinary work has occurred in cognitive science settings, but has not appeared within the more conservative journal setting. If one were to examine a somewhat less selective setting, like a conference, one might find a higher proportion of interdisciplinary work.

Second, it is possible that the discipline of psychology places a heavier emphasis on journal publications than do some of the other disciplines. For example, while conference publications might be considered of little value on a psychologist's vita, conference publications can be viewed quite favorably for computer scientists. Thus, we may find less of a dominance of psychology in a conference setting.

Third, in contrast to the journal articles, the affiliations of all authors are presented for the conference papers. It is possible that members from disciplines other than computer science and psychology are taking part in cognitive science activities, but only in conjunction with

psychologists and computer scientists. Thus, focusing on the first authors in the journal analyses may have partially masked the presence of the other disciplines.

Issues examined

The first goal of examining the annual conference is to see whether the journal results replicate. As we just argued, there are several reasons why one might expect to find different levels of interdisciplinarity in the annual conference. Towards this goal, we will again present analyses of departmental affiliations of paper authors, although this time also including more than just the first authors. However, we will not rely exclusively on departmental affiliations as a measure of disciplinary participation. We will also include results from questionnaires studies in which the authors where asked about their training backgrounds. This will allow us to test whether departmental affiliation measures used in the journal analyses were good measures of disciplinary participation.

The second goal of examining the annual conference is to investigate the collaborations found at the conference. In an interdisciplinary field, not only is it desirable for researchers from many different disciplines to participate, but it is also desirable for researchers from different disciplines to collaborate on research projects. The self-reported backgrounds of paper authors will be used to test for the presence or absence of such interdisciplinary collaborations.

Affiliation analyses

Figure 3 presents the percentage of departmental affiliations to each of the disciplines for first authors. As we see, the relative frequencies of each discipline at the conference are similar to those found in the journal. If anything, philosophy, linguistics, and neuroscience play an even smaller role in the conference (means each 2% or below).

In 1994 and 1995, a short questionnaire was sent to the authors of all multi-authored papers at the annual meeting (see Schunn, Crowley, & Okada, 1998; Schunn, Okada, & Crowley, 1995 for the details of these questionnaires). The questionnaires included questions about each of the authors' training backgrounds. Responses were obtained for over 60% of the papers, providing a good opportunity to examine whether the affiliation measure was a good surrogate measure for training background. Figure 4 presents the percentage of authors in each discipline according to the department affiliations and training backgrounds. As can been seen, there was a relatively similar distribution of listed affiliations and training backgrounds. The primary difference was that there were almost no authors who listed cognitive science as their training background. It is interesting to note that psychology and computer science were listed as training backgrounds more often than as affiliations, suggesting that psychology and computer science trained researchers are working in other settings (like industry, education, and, most notably, cognitive science departments).

Another question one might ask is whether examining only first author affiliations presents an accurate picture of participation. It is possible that other disciplines participate together with psychologists and computer scientists, but only as second, third, or fourth authors on the papers. To examine this issue, we coded the affiliations of all authors for the 1994, 1995, and 1996 annual conferences. While the majority of the papers had more than one author, a minority had three authors, and very few had four or more authors. Therefore, only the first through fourth authors were included in the analyses, and the results were collapsed across the three years. Figure 5 presents the percentage of authors in each discipline as a function of authorship order. The percentages are remarkably stable across the different authorship positions, with the possible exception that the proportion of neuroscientists is slightly higher in the third

and fourth positions. The slight rise in proportion of neuroscientists is not remarkable: neuroscience projects often require more researchers (and hence more authors) than do projects in psychology, computer science, philosophy, linguistics, and education. It may also be that, as brain research has advanced, there has been increasing interest on the part of funding agencies, researchers and the public at large in discovering the implications of this work for education and other applied fields, encouraging cross-disciplinary collaboration with neuroscientists (e.g., see the chapter by Bruer, this volume).

Comparing listed affiliations for all authors directly against self-rated training backgrounds (excluding the ambiguous affiliations of industry labs, government labs, and cognitive science), we find 80% agreement. In other words, rated training backgrounds usually matched the affiliations that were listed. The authors in cognitive science departments were for the most part trained as psychologists (68%) and computer scientists (21%), with a few trained as linguists (5%). Thus, we see a dominance of psychology and computer science even within the new cognitive science institutes and departments.

The 20% mismatches in affiliation present an interesting piece of data. They could be viewed as mistakes in the authors' ratings. More likely, however, is that they are cases of interdisciplinary hires. How are these hires distributed? The two most common categories are computer scientists in psychology departments (31%) and psychologists in computer science departments (23%). Then there are a few philosophers in computer science departments (10%). The remaining cases consist of computer scientists and psychologists in schools of medicine or schools of education (5% frequency of each case). Thus, we see primarily cross-fertilization of psychologists and computer science, with some additional spreading of psychologists and computer scientists to other disciplines.

In sum, there is a very consistent picture of disciplinary participation at the annual conference. As with the journal, the conference is dominated by psychology and computer science, with little participation of the philosophers, linguists, educators, and neuroscientists. These results are true across the years and across authorship order. They also do not depend upon whether self-reported background or listed departmental affiliations are used.

Proportion of interdisciplinary collaborations

The second goal of examining the annual conference was to investigate the collaborations found at the conference. Most of the papers were multi-authored. How many of these multi-authored papers involved collaborations of researchers from different disciplines? To test for the presence or absence of such interdisciplinary collaborations, we used the 1994 and 1995 questionnaire data.

As we described earlier, these questionnaires were sent out to the authors of all multi-authored papers at these two conferences. The authors were asked about the primary training background of each of the authors. Using these responses, each paper was classified into intradisciplinary (all from the same background) or interdisciplinary (at least one author from a different background). The authors were also asked about the relative status of each author (e.g., faculty, postdoctoral associate, graduate student, undergraduate student, etc). Responses were used to classify each paper into a peer collaboration (authors of same status) or apprenticeship collaboration (authors of different status). Of interest was whether interdisciplinary collaborations happened primarily in peer or apprenticeship collaborations.

At the 1994 conference, 47% of multi-authored papers were interdisciplinary. At the 1995 conference, 57% of multi-authored papers were interdisciplinary. Thus, while the conference is dominated by psychology and computer science, there is a high proportion of

interdisciplinary collaboration. This level of interdisciplinary collaboration proved to be equally prevalent for peer and apprenticeship collaborations. At the 1994 conference, 50% of peer collaborations were interdisciplinary and 38% of apprenticeship collaborations were interdisciplinary. At the 1995 conference, the corresponding numbers were 50% and 59%. Thus, interdisciplinary collaborations neither seem to require that all participants have equal status nor do they seem to require an apprenticeship relationship. Okada, Crowley, and Schunn (1996) found similarly high levels of interdisciplinary collaborations within the Japanese Cognitive Science Society meetings (41% of peer collaborations and 54% of apprenticeship collaborations). This suggests that interdisciplinary collaboration is a central part of cognitive science more generally, rather than just the activities of the Cognitive Science Society.

Did all disciplines participate in these interdisciplinary collaborations? To answer this question, we analyzed how often each discipline was paired with each other discipline at the 1994 and 1995 conferences. For simplicity, only the first two authors were considered. Almost all of the interdisciplinary collaborations involved either cognitive psychologists or computer scientists. Table 1 presents the frequency of each discipline combination (the first three columns), as well as the frequency of intradisciplinary collaborations for comparison (the rightmost column). The order of authorship is not represented. Interestingly, all of the disciplines except for cognitive psychology had at least as many or more interdisciplinary than intradisciplinary collaborations.

Many readers of our work have found our reported proportion of interdisciplinary collaborations surprisingly high. The barriers to interdisciplinary collaboration are formidable (e.g., see the chapters of Epstein and of Klein in this volume). What forces would lead so many researchers to collaborate with researchers from other disciplines? One hypothesis is that

interdisciplinary collaborations result in more successful work. To investigate this issue, the participants of the 1995 conference were asked how successful they thought the work reported in their paper was. Interdisciplinary collaborations were not rated more successful than intradisciplinary collaborations (58% versus 56% rating their projects very successful, respectively). As a converging piece of evidence, interdisciplinary collaborations were no more likely to be a paper (vs. a poster), which is determined by reviewer ratings, than were intradisciplinary collaborations (65% vs. 67% respectively). Finally, as a follow-up three years later, we sent email to the authors of the 1995 conference papers asking them whether the work reported at that conference had been published elsewhere in the form of a book chapter or journal article. It is possible that the authors and reviewers were not able to immediately evaluate the successfulness of interdisciplinary work, which may require a longer time to come together. We received responses from over 65% of our original set of papers, a surprisingly high rate given that this was an email survey and that many of the original authors had changed institutions. However, once again there was no difference in the successfulness of inter versus intradisciplinary collaborations (61% versus 63% reporting subsequent publications elsewhere).

What about the details of the collaborations? Participants of the 1995 conference were asked to estimate how often communication had occurred within the collaboration, the means of communication (face-to-face meetings, e-mail, etc.), the mesh or clash of the collaborators' background knowledge and intellectual styles, and the benefits and frustrations of the collaboration. Differences between inter and intradisciplinary collaborations were observed on several dimensions. First, participants were more likely to say that their co-authors frequently came up with alternative hypotheses in an interdisciplinary collaboration situation (45% versus 28%). Second, the interdisciplinary collaborators were more likely to say they had a different

research style than their co-authors (44% versus 28%). Third, interdisciplinary collaborators were more likely to say that they had an equal status relationship (86% versus 65%). This result held even when the relationship was inherently one of unequal status (100% versus 88% reporting equal status for peer collaborations, and 82% versus 58% for apprenticeship collaborations). Finally, three benefits were rated as occurring more often in the interdisciplinary collaborations than in intradisciplinary collaborations: having different ideas (75% versus 43%), having a stimulating relationship (81% versus 43%), and challenging each other's ideas (56% versus 39%).

Was there evidence that having different backgrounds contributed to the structure of the collaboration? For the 1994 conference, we asked the first authors to report which author played a primary role in each phase of the research: selecting the research question, designing the study or simulation, providing the resources for the study or simulation, running the studies or simulations, and writing the paper. Comparing inter and intradisciplinary collaborations, we found no differences in the number of roles to which the first author contributed (mean number of 3.9 vs. 4.0, respectively). However, the second author of interdisciplinary collaborations contributed to more roles than did the second author of intradisciplinary collaborations (means of 2.8 vs. 1.8, respectively). This pattern held for both peer and apprenticeship collaborations.

We conducted a similar analysis for the 1995 conference. For that conference, we had asked all authors (rather than just first authors), and we had asked each author only about themselves (rather than to report on the contributions of the other authors). Moreover, rather than ask who contributed to which roles, we asked the authors to rate the percentage of the work that they did for each of the roles and overall. Figure 6 presents the mean ratings for overall percentage of work. Once again, we see no differences for the first author, and greater work

levels for the second and third authors for interdisciplinary collaborations relative to intradisciplinary collaborations. Turning to the different roles, this pattern of differences held primarily for the roles of designing the study/simulation and analyzing the data. There were no differences between intra and interdisciplinary collaborations for coming up with the research questions and writing the paper.

Summary of findings

The state of interdisciplinarity in the cognitive science society can be viewed as the proverbial glass: half-empty or half-full. As the glass half-full, we saw a high proportion of interdisciplinary collaborations. This very high rate of interdisciplinary collaborations seemed related to better divisions of labor and other details of the structure of the collaboration rather than differences in the successfulness of interdisciplinary collaborations. Another positive feature of interdisciplinarity in the cognitive science society was a historical trend for an increasing frequency of individuals trained in cognitive science per se and using multiple methodologies. As the glass half-empty, we saw a domination by psychology and computer science, as well as the presence of pure psychology (e.g., psychologists working together presenting only data from psychology experiments) and pure computer science. These features have been true of the cognitive science society from its inception. In sum, cognitive science can be seen as interdisciplinary now and then, rather than completely intradisciplinary or completely interdisciplinary.

## Beyond the Cognitive Science Society

Perhaps this domination by psychology and computer science is just a problem in the Cognitive Science Society outlets, not a factor in cognitive science more generally. To explore

this possibility, we examined two other journals that are commonly considered prominent outlets of cognitive science research: Cognition, and Behavioral and Brain Science. Cognition is a bimonthly journal with approximately two to six articles per issue. It has been published since 1972. Its subtitle is: International journal of cognitive science. BBS is a quarterly journal that typically publishes two to four large articles in each issue. Each article presents in detail a particular author's thesis, typically a controversial one. The article usually reviews the authors' previous research rather than presenting new evidence. The article is then followed by 10 to 50 commentaries by other researchers, followed by a response by the author to each of the comments. BBS was first published in 1978 and describes itself as a journal for research in psychology, neuroscience, behavioral biology, and cognitive science. Thus, it actually has a scope larger than that of cognitive science.

We coded the departmental affiliations of article first authors and the methodologies presented in each article in 1996 and 1997. Figure 7 presents the percentage of authors with each discipline affiliation for these two journals as well as Cognitive Science for comparison. As can be readily seen, Cognition is even less well balanced than Cognitive Science. It is almost completely dominated by psychologists (69%). The levels of neuroscience are slightly higher than those found in Cognitive Science, but the levels are still well below 10%. Most importantly, there is no computer science to be found in Cognition during the years examined. Examinations of Cognition articles from the early 2000s suggests this trend of psychology domination continues.

BBS presents yet another picture of cognitive science. While psychologists are the largest plurality, they are not a majority in this journal (37%). Moreover, neuroscience plays a large role in this journal (26%). However, there continues to be little presence of linguistics (5%),

philosophy (11%), and education (0%). Moreover, very few computer scientists take part in BBS (5%).

Turning to the methodologies used in each of these journals, Figure 8 presents the percentage of articles using each of the methodologies for Cognitive Science and Cognition. The same categories as discussed earlier were used. BBS is not included in this analysis because articles do not typically present new research. From this figure, it is clear that Cognition is heavily dominated by psychological empirical studies. There is, however, slightly more linguistic analysis and philosophical argumentation in Cognition, although still in very small quantities. Other than psychological empirical studies, it is only the neurological data methodology that exceeds 10% in Cognition.

In sum, while Cognition and BBS may present slightly different perspectives of cognitive science, they still do not have an equal balance among the disciplines. The question remains: why do linguistics, philosophy, neuroscience and education not play larger roles in cognitive science?

## Where did linguistics, philosophy, and neuroscience go?

Why have linguists, philosophers, and neuroscientists not taken a greater role in cognitive science? The answer to this question is likely to provide insights into the creation and evolution of a new discipline. Here we will consider several different possible factors in turn, beginning with the simplest factors. It is likely that no one factor is responsible for influencing so many disciplines, and the important factors are likely to vary by discipline.

Problems at the top or at the bottom

One simple explanation for the disciplinary distributions within cognitive science is that it is the result of explicit or implicit editorial practices in the journal reviewing and conference reviewing and organization. However, many factors argue against this hypothesis. First, the explicit editorial policies of the journals and the annual conference clearly invite submissions from the other constituent disciplines of cognitive science. Second, in discussions of this issue with many of the past conference organizers, editors, and society presidents, the majority of them stated that they made several efforts over the years to include the other disciplines. One of the authors of this chapter was chair of the annual cognitive science conference in 2002 and can report first hand that psychology dominated the conference despite many attempts to include other discipline participation and use discipline-neutral reviewing criteria. Third, there is concrete evidence of these efforts. For example, there were several special invited issues highlighting activities from other disciplines in the journals Cognitive Science and Cognition. At several of the annual conferences, there were special invited symposia highlighting activities from other disciplines. Thus, it is unlikely that the absence of linguistics, philosophy, and neuroscience is the result of explicit editorial and organizational biases (see Greeno, Clancey, Lewis, Seidenberg, Derry, Gernsbacher, Langley, Shafto, Gentner, Lesgold, & Seifert, 1998).

Size of the disciplines

Another very simple explanation of the disciplinary distributions within cognitive science is the relative size of each discipline. In other words, psychology and computer science may simply have more active researchers than philosophy, linguistics, and neuroscience. In the case of neuroscience, this explanation is simply humorous. Neuroscience is itself a combination of several disciplines (e.g., psychiatry, neuroananatomy, neurophysiology, neuropsychology,

neurochemistry, etc.). Its main conference, The Society for Neuroscience, attracts about 40,000 attendees—more than the largest psychology and computer science conferences put together.

The case of philosophy and linguists may not be as implausible as there are fewer research philosophers and linguists than research psychologists. However, available overall productivity data do not support this hypothesis for these disciplines either. Simple on-line searches were conducted using the WorldCat, Journal, Proceedings, and Conference databases available in FirstSearch of work produced from 1990–1995. These searches revealed that there were approximately as many psychology conference papers as philosophy papers, and linguistics produced over 25% more conference papers than did psychology. Moreover, while linguistics produced fewer journal articles and books than psychology, philosophy produced as many. Thus, while differential size of the disciplines may contribute, the productivity data suggests it is not likely to be the source of differential participation in cognitive science.

Recognition of cognitive science by mainstream elements

We found that linguistics has historically been the third most cited of the constituent disciplines behind psychology and computer science. This suggests that linguistics is considered relevant to cognitive science by cognitive scientists. Yet, for both the journal and the conference analyses, participation by linguists has never exceeded 4% of all articles or conference papers. Why do the linguists not participate?

One possible explanation is that linguistics does not consider cognitive science to be relevant. To investigate this explanation, we conducted several citation analyses using the Social Science Citation Index. First, we counted the number of citations to the journal Cognitive Science in the journal Linguistic Inquiry, for all main articles (ignoring news items, remarks, and reply articles) for the years 1980, 1987, and 1994. For comparison, we also conducted the same

analysis for the journal Psychological Review. Both Linguistic Inquiry and Psychological Review are the top mainstream journals within each of those two disciplines, as measured by citation index impact factor. As can be seen in Figure 9, Cognitive Science articles were regularly cited in Psychological Review, but were never cited in Linguistic Inquiry. Thus, mainstream linguistics articles appear not to cite Cognitive Science articles.

As a second citation analysis, we examined how often Cognitive Science articles by linguists are cited by anyone in contrast to Cognitive Science articles by psychologists and computer scientists. The citation analysis was done for papers from 1980, 1986, and 1991, years selected randomly from the three time periods used for the other journal analyses. Citations were counted 2, 4, and 8 years after publication. Figure 10 presents the mean number of citations collapsed across publication year. Psychology papers (N=14) received the largest number of citations (mean of 3.4 per year per paper). Computer science papers (N=10) were next most cited (mean of 2.1 per year per paper). Linguistic papers, what few there were (N=2), were the least cited (mean of 1.3 per year per paper). Perhaps it is because mainstream linguists do not read Cognitive Science papers that the citation rates are so low for linguistics papers when they do appear in Cognitive Science. Whatever the cause, there are clear external reinforcers for linguists not to publish in Cognitive Science.

It is difficult to do corresponding analyses for philosophy, both because philosophers publish even less frequently in Cognitive Science and because philosophy does not have a central, high-impact journal. However, the existence of the vibrant Society for Philosophy and Psychology suggests that many psychologists consider philosophy to be relevant to psychology and many philosophers consider psychology to be relevant to philosophy.

Where is the money?

It is likely that availability of funding has an impact on where people receive training, to which departments they chose to belong, what kinds of research is conducted, and who can afford to attend conferences. Various public and private funding sources have provided large quantities of money to cognitive science research over the years (e.g., NSF, DARPA, ONR, AFOSR, McDonnell, Mellon, and Spencer). Many of these funding initiatives have had an applied bent, particularly towards education and training. It may be that this applied bent may be part of the reason that researchers from different disciplines were brought together—applied problems tend not to reside nicely within only one discipline, and usually require contributions from multiple disciplines. However, it is beyond the scope of this chapter to speculate on how funding patterns may or may not have excluded certain disciplines. Moreover, the relationship between funding and research is typically bidirectional—funding for particular approaches spurs productivity in the area and at the same time new productive approaches to an area tend to draw more funding (see the Bruer chapter, this volume, for examples of how a grant agency contributed to the growth of interdisciplinary work).

Competition for time and money

In addition to limitations imposed by funding trends, there are resource allocation issues providing a general pressure against the creation and acceptance of new interdisciplinary journals and conferences. Academics typically have limited resources of both time and money when it comes to attending conferences and subscribing to journals and societies. As long as there are sufficiently relevant and interesting conferences, journals, and societies within a discipline for a researcher, they may be reluctant to devote extra resources to an interdisciplinary conference, journal, or society. For example, participation of computer science in cognitive science

decreased in the early 1980s when the American Association for Artificial Intelligence formed, creating a new journal and annual conference.

The funding issue is not likely to play a large role in the case of neuroscience. In this case, there are many other conferences (Neuroscience, Cognitive Neuroscience, Computational Neuroscience, and others) and journals (Journal of Neuroscience, Journal of Cognitive Neuroscience, Cognitive Neuropsychology , Neurocomputing, and others) that well-fit the interests of researchers interested in the intersection of psychology and neuroscience or computer science and neuroscience. The journal Cognition competes with Cognitive Science for the attention of philosophers and linguists interested in cognitive science. The annual meeting of the Society for Philosophy and Psychology competes for the attention of philosophers interested in cognitive science.

The funding resource issue may be more critical in the case of disciplines that are less well funded. For any particular researcher, this issue has both direct effects (Can I afford to attend this conference?) and indirect effects (Will my colleagues in my discipline notice my work in this interdisciplinary setting?). However, future research is required to assess whether this factor actually played a role in the lack of participation of certain disciplines in the Cognitive Science Society, particularly since the Cognitive Science Society journal and conference are not all that expensive.

### Micro cognitive sciences

There is also no particular reason why the many constituent disciplines and possible pairwise combinations among constituent disciplines of cognitive science should cohere at the level of one big cognitive science social world. There are journals that correspond to most if not all of the possible pairwise combinations of psychology, computer science, linguistics,

philosophy, anthropology, education, and neuroscience. Thus, there may be many micro cognitive sciences that reflect different pieces of the overall cognitive science. For example, research on education-related cognitive science is often published in Cognition & Instruction or the Journal of the Learning Sciences. Linguistics-related cognitive science is often published in Cognition or Computational Linguistics. Neuroscience-related cognitive science is often published in the Journal of Cognitive Neuroscience. Since the combination of psychology and computer science has "owned" the Cognitive Science Society outlets from the beginning, it may be for this reason that it is the only micro cognitive science that tends to take part in that social world. Even within the combination of psychology and computer science, there are other cognitive science social worlds. For example, researchers interested in human-computer interaction have their own large conference and journals. Thus, it may be misleading or naïve to think of cognitive science as a unitary discipline or to expect that it should be one.

Epistemological & methodological stances

The preceding section does not address the issue of why different pieces of cognitive science might not cohere together. One factor that is likely to play a very large role is differences in epistemological and methodological stances. If individuals cannot agree on what counts as an interesting question, what counts as acceptable data, and/or what counts as acceptable theory, they are unlikely to participate in the same social worlds. In our questionnaire survey of authors of Cognitive Science conference papers, we asked about the frustrations of collaboration. The only frustration that was listed more often with interdisciplinary collaborations than intradisciplinary collaborations was having ideas that were too different. Okada, Schunn, Crowley, Oshima, Miwa, Aoki, and Ishida (1995) interviewed 21 cognitive scientists about factors that are important in their collaborations. When one of the researchers was asked how he

evaluates whether a person would make a good collaborator, he responded: "(The important thing is) whether or not a person shines his eyes at the right times when we are talking about interesting ideas. As a joke, we call it the 'shining eye test.' ... It indicates whether or not we can share interesting problems." Another researcher was more blunt: "If we don't share interests, I cannot work with him."

With respect to the Cognitive Science Society, it tends to emphasize empirical and/or applied work that advances theory from within computer science, psychology, education, and linguistics. That is, the models should actually run rather than exist only on paper, the psychological and educational studies should involve rigorous experimental methodology with careful data analyses, and the theories should address issues of performance and learning rather than just competence. Linguistics, philosophy, education, and anthropology research tend to clash with the Cognitive Science Society approach on several of these dimensions. There are also epistemological clashes. In the great debates of situation cognition versus symbolic processing (e.g., Anderson, Reder, & Simon, 1996, 1997; Greeno, 1997; Vera & Simon, 1993), for example, the social worlds of the Cognitive Science Society have tended to favor the symbolic processing side.

Although the organizers of the Society have often tried to be open to alternative approaches, as evidenced by journal editorial statements (e.g., Greeno et al., 1998) and calls for conference participation, it may be difficult to overcome this fundamental clash. Reviewers will continue to apply the standards from their own epistemological/methodological approach, and researchers will not participate when they find the work being presented to be opaque and/or uninteresting from their own perspective.

## Conclusion

In this chapter, we have examined the historical and recent state of interdisciplinarity in cognitive science. We have found it to be a case of interdisciplinarity now and then: one often finds researchers from different disciplines working together using methodologies from multiple disciplines, but the field continues to be dominated by two constituent disciplines, psychology and computer science. While much of this chapter has focused on the glass half-empty, the positive findings regarding interdisciplinarity in cognitive science should not be forgotten. We found significant evidence for many researchers overcoming large barriers to actually work together with researchers from other disciplines or at least reading literature and learning methodologies from other disciplines. Moreover, we described some of the benefits of these interdisciplinary collaborations.

Turning back to the glass half-empty, many questions remain to be answered: Is this domination hindering progress in cognitive science, or is it a necessary state of affairs? Would deep interdisciplinarity lead to more innovative work, or will the best science emerge from limited interdisciplinary exchanges around shared epistemological stances? How should the next generation of cognitive scientists be trained, deeply in a single discipline or broadly across several? What kinds of infrastructure innovations will lead to true interdisciplinary work and what kinds will simply reinforce existing disciplinary boundaries? In an academic climate where junior faculty are often advised that tenure comes from publishing conservative research in traditional discipline-specific journals, are we minimizing the contributions of exactly the scientists with the best chance of forging true links between disciplines? These are empirical questions, but they have rarely been the subject of empirical research. We hope our work will provide data that may help guide the continued emergence of the field of cognitive science.

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Table 1. The frequency of interdisciplinary and intradisciplinary collaborations among the disciplines (between first and second authors) for the 1994 and 1995 annual conferences.

| Discipline | Interdisplinary Collababorations with | | | Intradisplinary Collaborations |
|---|---|---|---|---|
| | Cognitive Psy | Comp Sci | Other | |
| 1994 | | | | |
| Cognitive Psych | - | 13 | 8 | 24 |
| Computer Science | 13 | - | 7 | 14 |
| Educational Psych | 3 | 0 | 0 | 1 |
| Philosophy | 1 | 2 | 0 | 0 |
| Linguistics | 2 | 3 | 0 | 2 |
| Other | 2 | 2 | 0 | 1 |
| 1995 | | | | |
| Cognitive Psych | - | 12 | 6 | 20 |
| Computer Science | 12 | - | 7 | 8 |
| Developmental Psych | 4 | 3 | 0 | 0 |
| Philosophy | 0 | 2 | 1 | 0 |
| Linguistics | 1 | 1 | 0 | 0 |
| Other | 1 | 1 | 2 | 1 |

**Figure 1. Percentage of 1st author affiliations for each discipline in the journal Cognitive Science.**

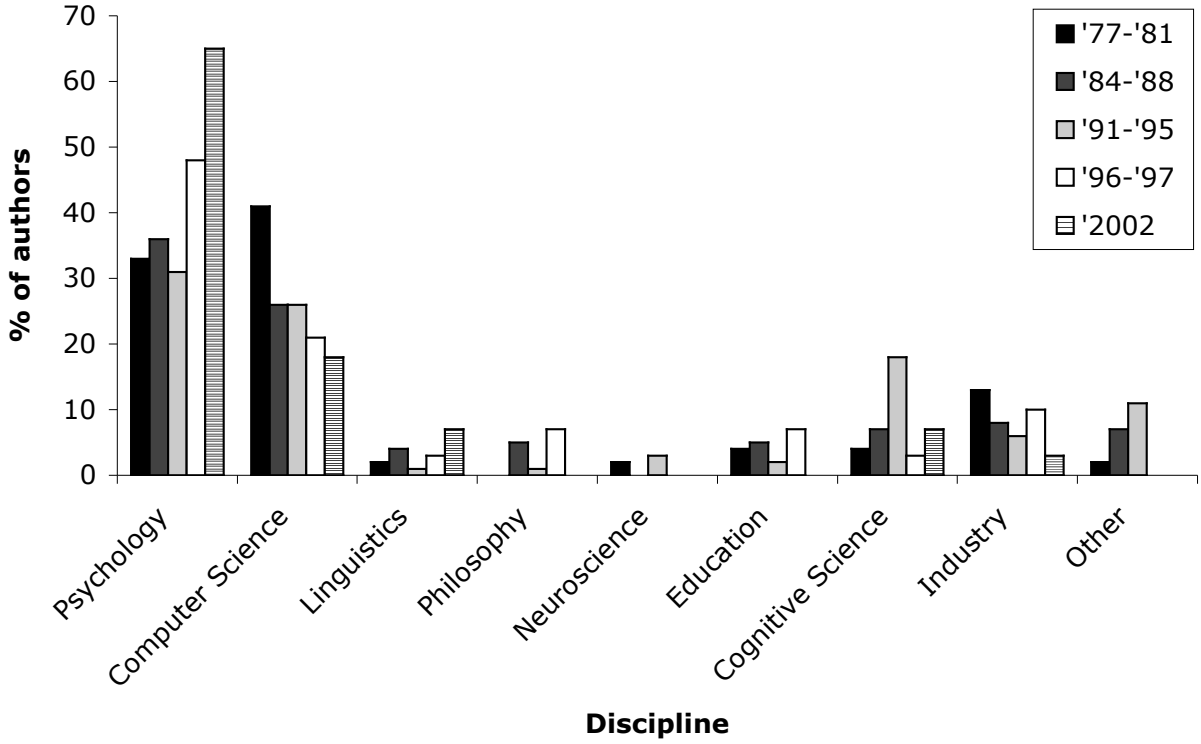

**Figure 2. The percentage of citations to work in each discipline within Cognitive Science journal articles.**

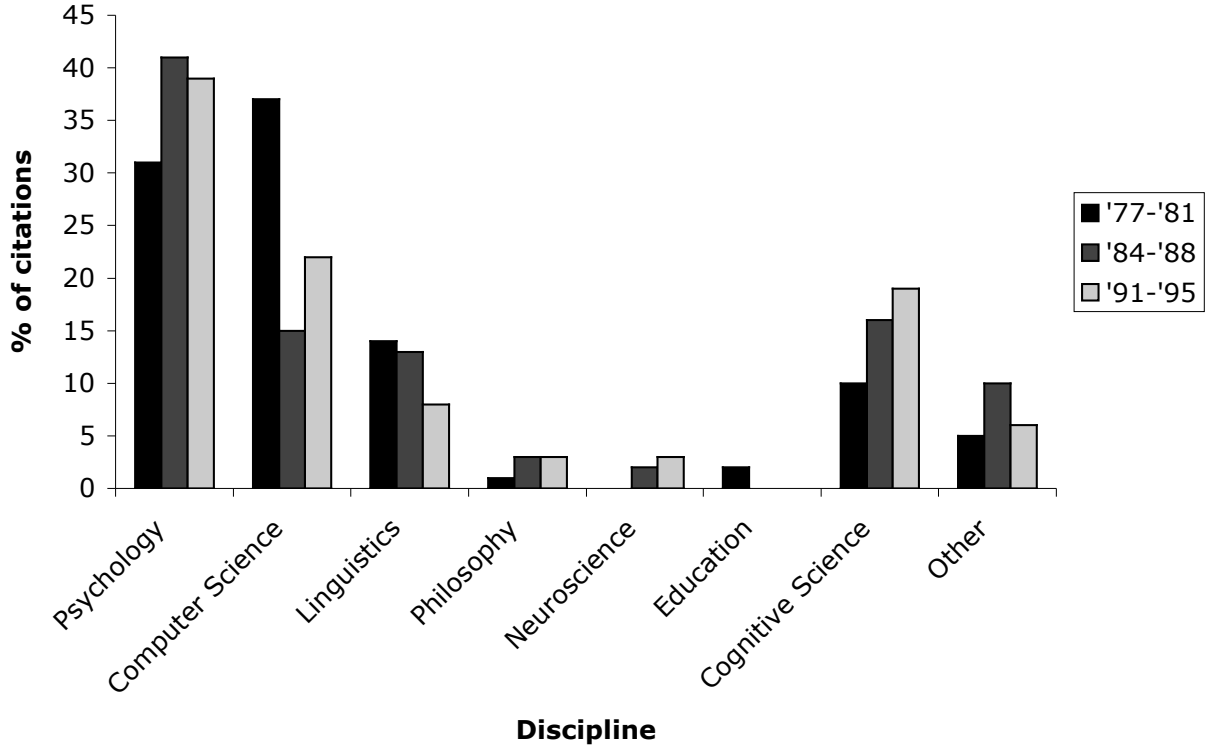

**Figure 3. Percentage of 1st author affiliations for each discipline at the Cognitive Science conference.**

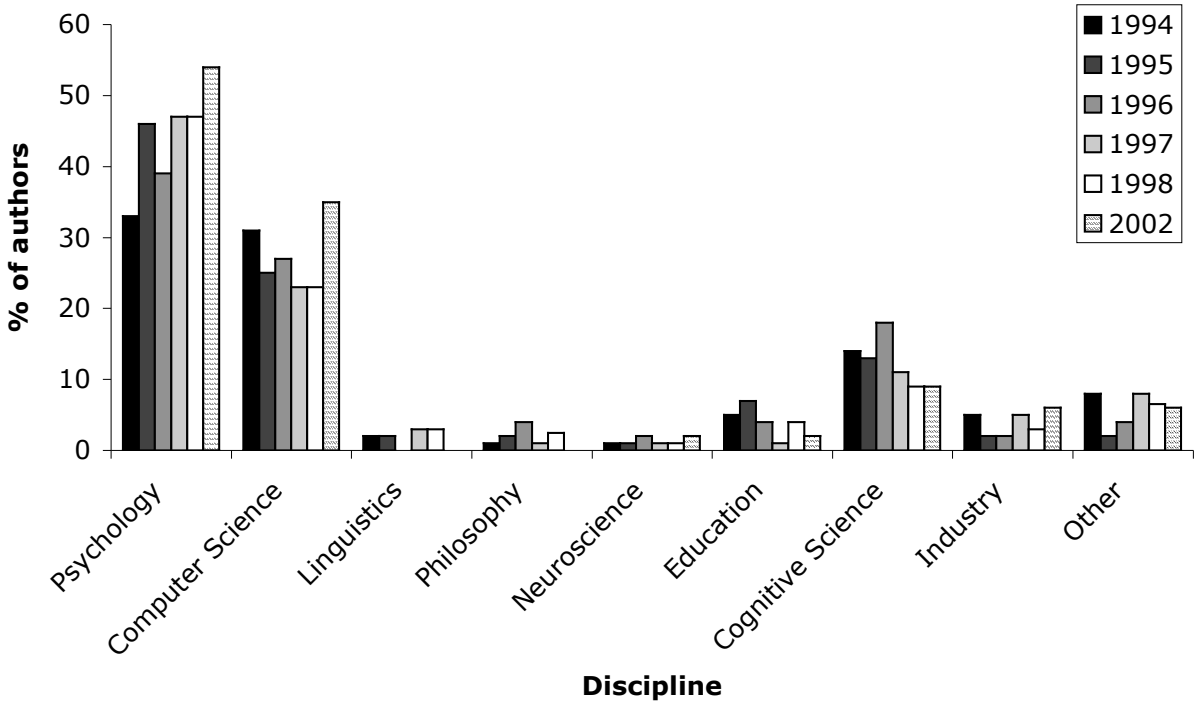

**Figure 4. Percentage of 1st authors at the annual conference with affiliations or training backgrounds in each of the disciplines.**

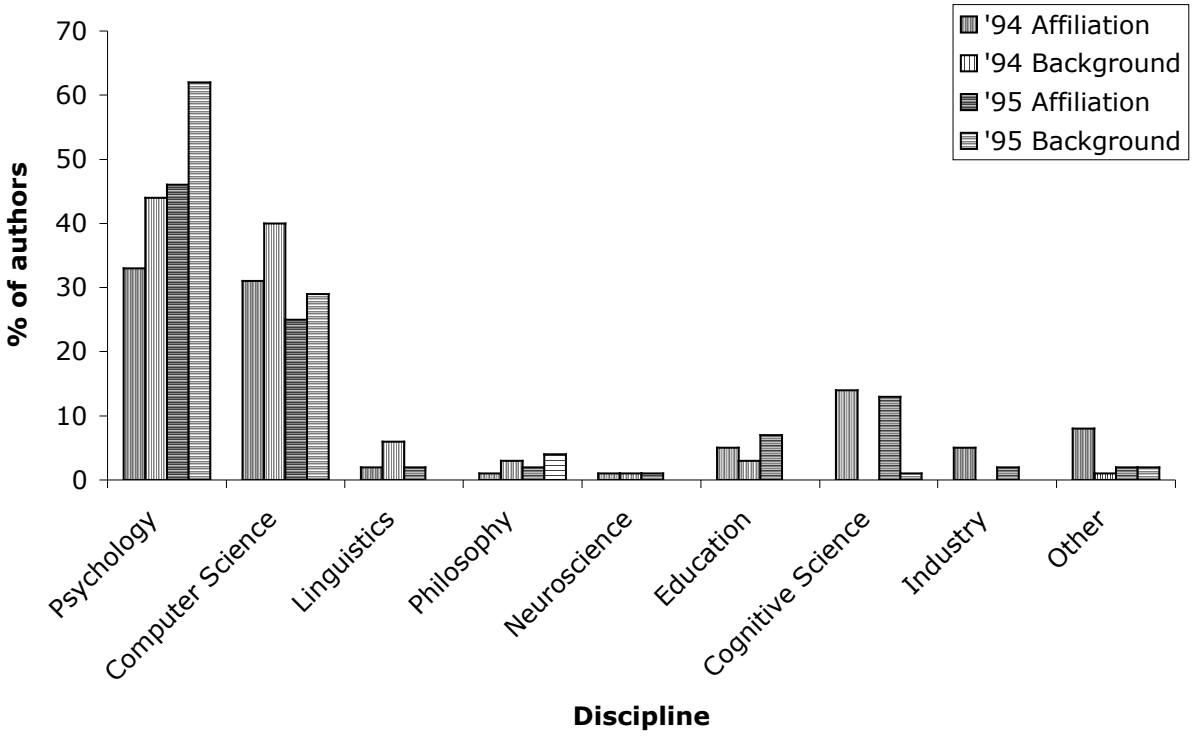

**Figure 5. Percentage of authors at the 1994, 1995, and 1996 annual conferences with affiliations in each of the disciplines as a function of authorship order.**

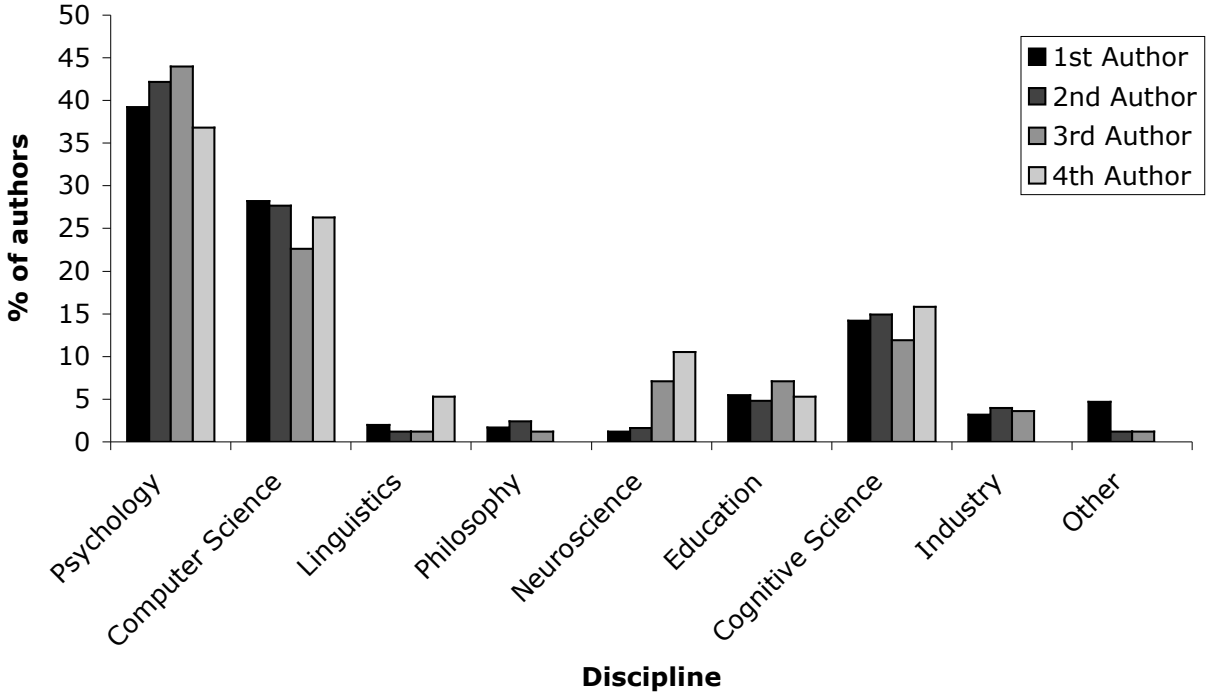

**Figure 6. Mean self-rated percentage of the overall work to which each author contributed as a function of inter and intradisciplinary collaboration for the 1995 conference.**

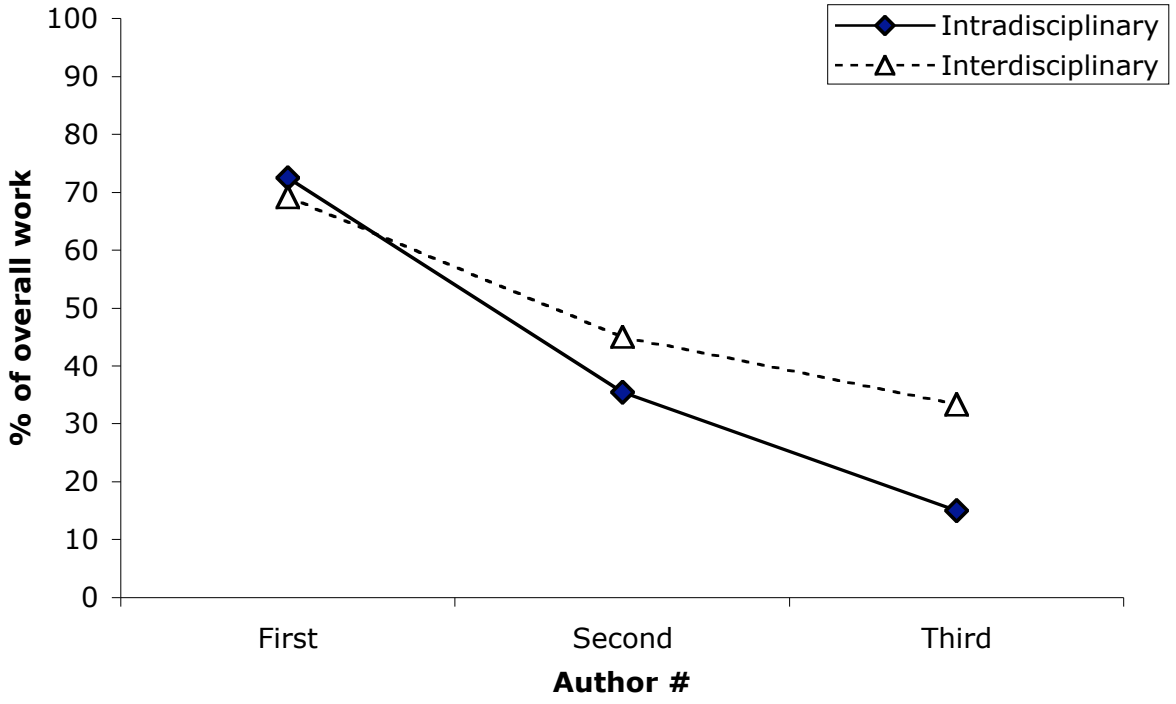

**Figure 7. Percentage of 1st author affiliations for each discipline in the journals Cognitive Science, Cognition, and Behavioral and Brain Sciences for 1996 and 1997.**

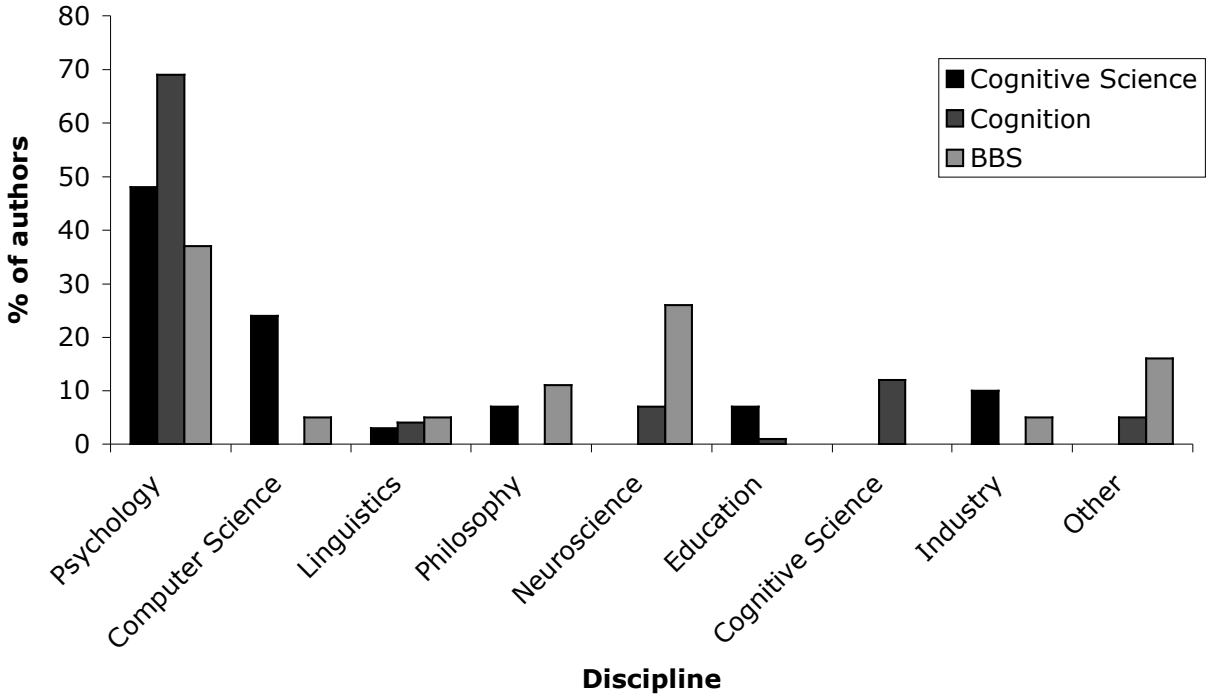

**Figure 8. The percentage of papers using each of the disciplinary methodologies for the journals Cognitive Science and Cognition in 1996 and 1997.**

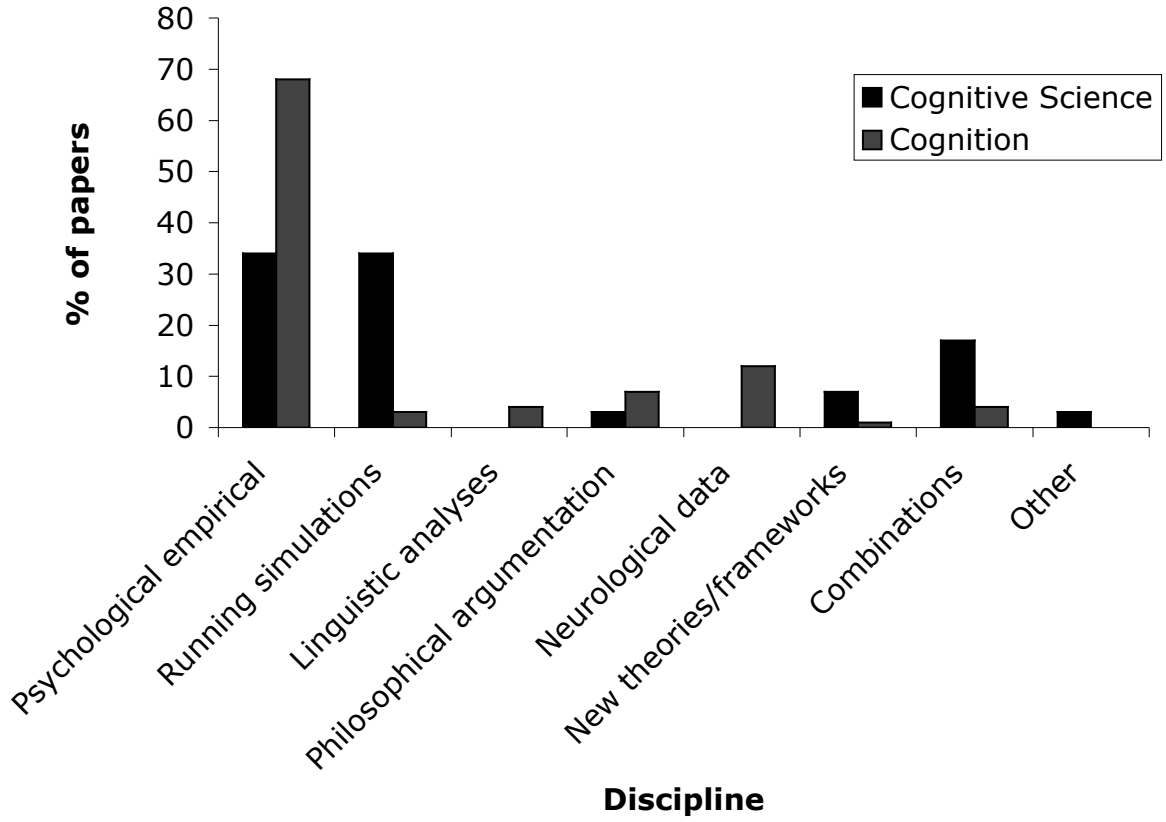

**Figure 9. The percentage of articles in Psychological Review and Linguistic Inquiry citing work in the journal Cognitive Science.**

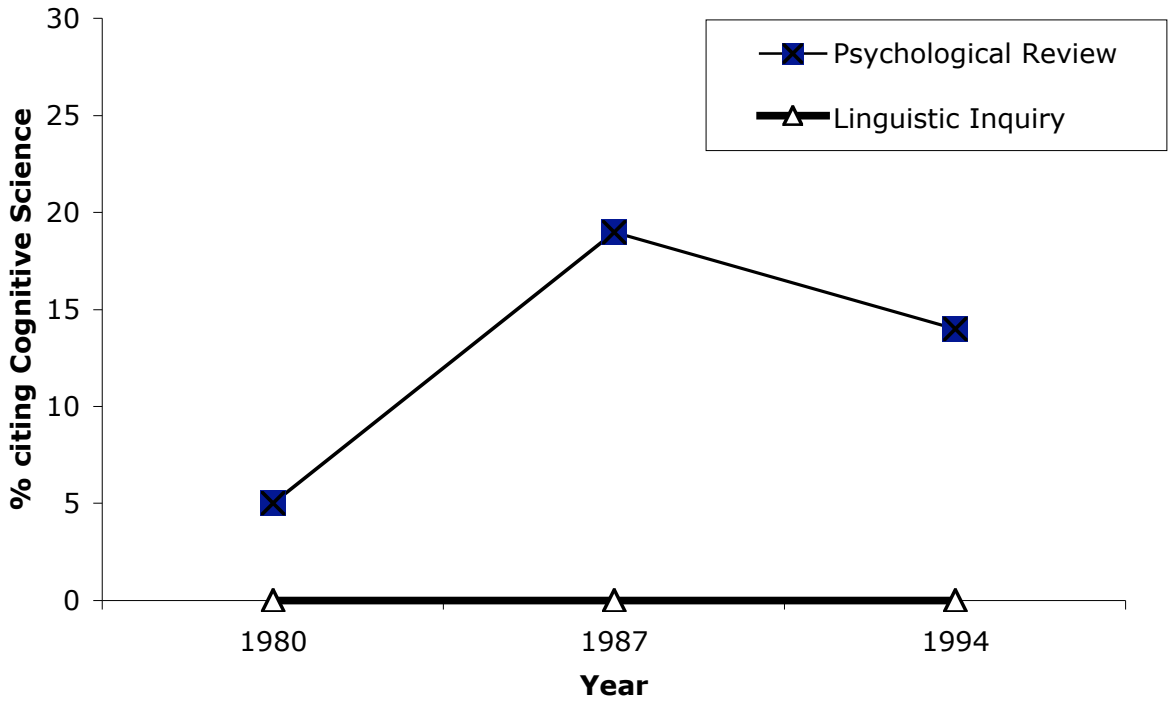

**Figure 10. The mean number of citations to Cognitive Science articles published by psychologists, computer scientists, and linguists two, four, and eight years after publication.**