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What Should Cognitive Science Look Like? Neither a Tree Nor Physics

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Abstract

While pointing out important features of cognitive science, Núñez et al. (2019) also argue prematurely for the end of cognitive science. I discuss problematic analytic features in the application of hierarchical cluster analysis to journal citation data. On the conceptual side, I argue that the research programs framework of Lakatos may not be so wisely applied to cognitive science. Further, the diversity of structure in cognitive science departments may represent a rational, strategic adaptation by an interdisciplinary department to cognitive and other resource challenges rather than the sign of low progress on a discipline.

Keywords: Cluster analysis; Research programs; Competition; Maps of science; Sociology of science

1. Introduction

Useful development within organisms can occur without meta-cognitive reflection. A range of cognitive science work over the decades has developed, tested, and refined models of adaptation and change that has shown that reflection is not necessary for change (e.g., Chang, Janciauskas, & Fitz, 2012; Reder & Schunn, 1996; Wright & Whittlesea, 1998). At the same time, extensive work has also shown that meta-cognitive reflection does add value: Organisms can change more rapidly and more effectively with

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meta-cognitive reflection (Schunn, Lovett, & Reder, 2001; Taylor, Krakauer, & Ivry, 2014). Similarly, a field does not need but can benefit from reflection on itself. Núñez et al. (2019) present an interesting opportunity to do this reflection, with the hopes that further adaptation can be supported within each of the three social worlds (Unruh, 1980) of cognitive science conferences, journals, and training programs.

Just as we emphasized in our own analysis of cognitive science social worlds (Schunn, Crowley, & Okada, 1998, 2005), now several decades ago, Núñez et al. draw attention to many indicators that cognitive science cannot be characterized as an interdisciplinary field consisting of uniform and equal participation of constituent traditional disciplines. There is no point debating that relatively simple descriptive observation: Cognitive psychology has always had and continues to have the loudest voice, and there is huge regional variation in participation. To this basic observation, Nunez et al. also note huge variation in underlying assumptions and methods, which is likely closely correlated with variation in disciplinary participation. From this observation, one might argue the more modern naming scheme that uses a plural (i.e., Cognitive Sciences), similar to Biological Sciences and Learning Sciences, is more descriptively accurate.

An aspect of Núñez et al.'s paper that is more worthy of debate is the characterization of cognitive science as a failed entity, either already having failed (given the past tense in the paper's title "What happened to cognitive science?") or one that is soon to fail (e.g., "raising questions about the future of the cognitive science enterprise"). I suggest this more controversial conclusion is unwarranted. In support of this claim, I first raise concerns about the cluster analysis methods used in the paper to show that the analysis approach (at least for the citation patterns analyses) had multiple important flaws. Then I discuss conceptual concerns with defining disciplinary success using the Lakatos framework, drawing attention to potentially problematic underlying assumptions about what the goal of a new interdisciplinary field should be, arguing that uniformly structured social worlds (conferences, journals, and especially training programs) are unlikely to be the best way forward.

2. Analytic concerns

Analytic, algorithmically derived models are the foundation of many sciences, including cognitive science. Science benefits from such models in that they are relatively objective, easily communicated, and easily applied in replication work. In addition, the visualizations built from them tend to be especially persuasive. But it is important to remember the models have important biases and are not raw data but rather that they are best thought of as tentative inferences based on raw data. Of course, the function of models is not to perfectly capture underlying data but rather to draw attention to particular phenomena or relationships (Box, 1979). But nonetheless, some models present misleading perspectives.

The analytic techniques presented in the Núñez et al. paper offer some interesting information about the state of cognitive science and how it has progressed. However, I

argue there are some fundamental problems in the choice of models of citation patterns data and the interpretation of them. In particular, I discuss two problems related to the hierarchical cluster analyses of citation data.

2.1. Looking for trees where there is no forest

Núñez et al. apply hierarchical cluster analysis to journal citation data (considering both incoming and outgoing citations). While seemingly straightforward and comprehensive, it is important to realize that hierarchical cluster analysis is not only dated as a clustering technique, it is inherently flawed when applied to cases that theoretically should not be tree structures. By virtue of building upon multiple disciplines, cognitive science journals should be connected to multiple disciplines, not just clustering on its own; but hierarchical cluster analysis only finds tree structures. In contrast, models of discipline structure based on citation data are more typically rendered as maps. In fact, the maps of science, based on various sources of data, are not usually trees. Instead, they are usually represented using two-dimensional maps with complex interconnections and often with circles (see many examples at scimaps.org). Fig. 1 shows the UCSD Map of Science (Börner et al., 2012), which was based on an analysis of 7.2 million papers. Not surprisingly, disciplines do not have simple tree structure when considering their relationship with other disciplines, whether it be theories, results, or tools. It is important to note, however, it is just as problematic to assume *a priori* that a two-dimensional solution is best; broader model exploration is important.

What about when zooming in more closely to cognitive science? Some maps based on journal co-citation patterns have featured cognitive science as a node, and in a way that connects to many other disciplines (see Fig. 2). In the hierarchical cluster results presented by Núñez et al., the larger clusters only join at relatively high thresholds of dissimilarity, providing a clue that tree structure might not be a good way of characterizing

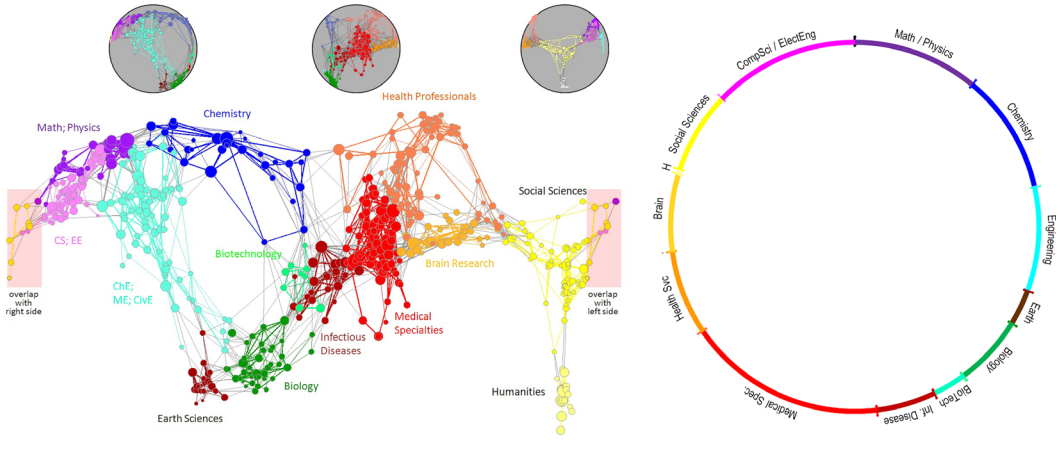

Fig. 1. The 2012 UCSD map of science (from Börner et al., 2012).

this data. Future work should be done to explore how well other, including higher-dimensional, models fit the data. Under the Bayesian modeling paradigm, schemes have been developed for automatically exploring different structure types (e.g., list, tree, ring, network) while also automatically finding best instances within each structure type (Kemp & Tenenbaum, 2008).

2.2. The chicken and the egg of automated clustering techniques

As Núñez et al. note, there is a strong presence within the authors of papers in the journal *Cognitive Science* (see their Fig. 2a) and faculty in cognitive science departments (see their Fig. 2c) who were trained in psychology departments. The implication of this fact is that these individuals, from a simple access-to-knowledge perspective, are more likely to cite psychology than non-psychology traditional papers (as also shown in their Fig. 2b). And the implication for analysis is that clustering techniques (especially hierarchical cluster analysis) based on co-citation patterns will be likely to sort cognitive science journals into psychology.

Despite this base-rate pressure, looking across the clusters produced from 2000, 2007, and 2014 (see their Fig. 3), we see both an increasingly strong cluster of the "core"

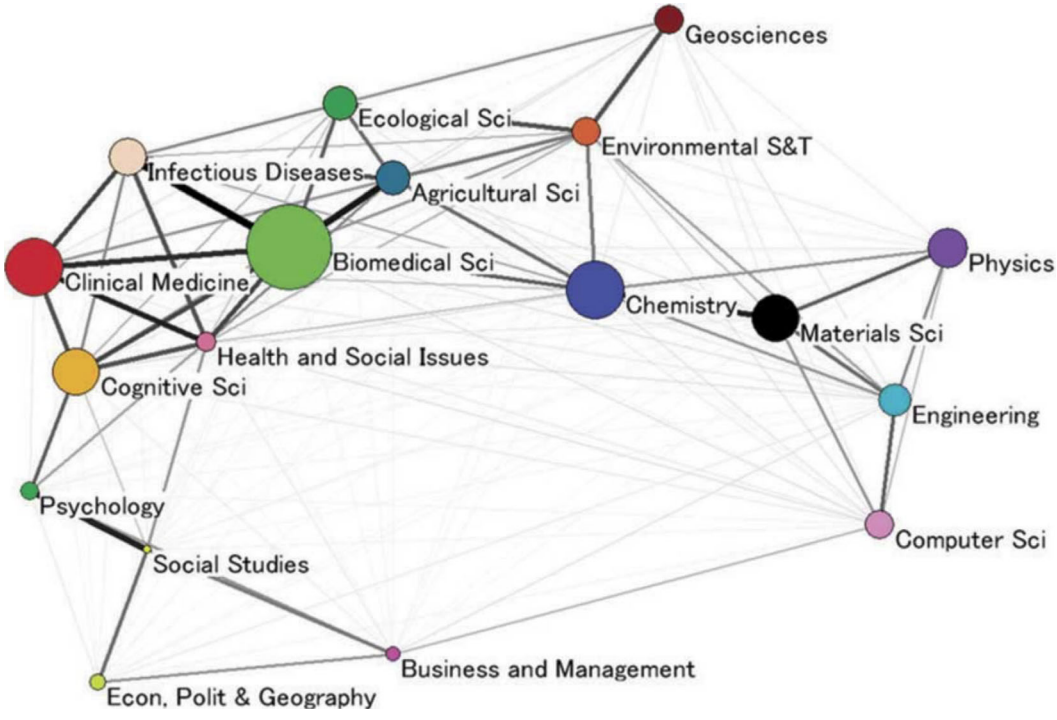

Fig. 2. Disciplinary map that features cognitive science based on journal co-citation patterns (from Rafols, Porter, & Leydesdorff, 2010).

cognitive science journals: *Cognitive Science*, *Cognition*, and (the later arriving) *topiCS*, and a greater distance of them to traditional cognitive psychology journals. It may be that the base-rate pressure will also complicate the results found using non-tree structures, or it may be that other network structures will be less sensitive to this problem than is a tree structure since a poorly fitting tree structure would be more likely to default to base-rate information.

As smaller point, there is likely a substantial connection of cognitive science journals to the journal *Psychological Review* at least in part because cognitive science is strong on theoretical models which tend to play a central role in *Psychological Review*. So that specific connection could be interpreted as reflecting the alignment of goals between cognitive science and *Psychological Review* rather than the dominance of psychology in cognitive science.

3. Conceptual concerns

Núñez et al. ground their meta-claims about the dysfunctional nature of cognitive science in the progressive/regressive research programs framework of philosopher of science Imre Lakatos (1976). Philosophy and history of science, particularly of that era, were heavily focused on the older sciences, especially physics. Such a focus had the advantage of time to observe long-scale changes and psychological distance from the change. However, there are reasons to doubt that the historical developments of physics are the only viable model or even that it should serve as the prototypical model. Indeed, the maps of science shown in Fig. 1 and especially Fig. 2 suggest that physics is somewhat atypical.

3.1. Neither cognitive psychology nor cognitive science is (or should be) physics

If the bar for deciding that a discipline exists in coherent form is that it has a shared foundational curriculum or a typical content structure, then cognitive psychology itself (or most of psychology) perhaps would not meet that bar. Physics and chemistry are older than cognitive science by an order of magnitude, and as a result, they have a settled foundational curriculum that reflects settled disciplinary canon. The introductory courses in physics and chemistry mostly contain content from over 100 years ago, and there are not "schools of thought" who argue about this content (even as they acknowledge that the older models are now known to be incomplete approximations).

By contrast, cognitive science, and even cognitive psychology, are much newer and have not yet come to an agreement on most of the core issues across various schools of thought. In cognitive psychology, we do not even agree on the main cause of forgetting, one of the first phenomena of cognitive psychology ever studied (Ebbinghaus, 1880); different schools of thought are still claiming victory for decay or interference explanations as the foundational factor (Altmann & Schunn, 2012). Within cognitive science, there is the cascading problem of being based in mostly "new" component disciplines

(cognitive psychology, computer science, cognitive neuroscience) that are each still hotly debating foundational assumptions and phenomena. To amplify this problem, cognitive science (as a newcomer) has a relatively small set of practitioners such that progress per year is necessarily slower than what a large number of practitioners could achieve.

The consequences of being grounded in open basic content is important for both department structure and bibliometric analyses. For department structure, schools of thought to which practitioners from one discipline align could influence the choice of other disciplines for which there are natural partnerships. For example, nativists in psychology will have closer matches to linguists and empiricists in psychology will have closer matches in computer science. Thus, we could conceive as variation in disciplinary content as derived from the constituent disciplines not yet being settled on foundational assumptions; as the constituent disciplines begin to settle, we might predict that so will the choice of constituent faculty by discipline. For bibliometric analyses, the diversity of schools of thought complexifies the emergence of a single node in clustering techniques from citation data. More complex analytic models of bibliometric may be able to overcome this issue, similar to natural language processing models coming to understanding underlying meaning despite the existence of many synonyms in natural language.

3.2. The many ways of balancing breadth and depth

A central concept in cognitive science is bounded rationality (Gigerenzer & Selten, 2002; Simon, 1972). Each cognitive system can only sense, process, or know so much information, with profound interactions among capacities of perception, memory, and cognition. For example, when more information is perceived or remembered, then the cognitive processor can be overwhelmed in trying to process all that content. As the grain size of analysis goes up to groups of individuals (e.g., in a laboratory or in a department), the foundational insight still applies since those too can be thought of as cognitive systems with bounded rationality (Simon, 1991).

When designing an optimal laboratory group or department that is trying to be spanning disciplines (whether multi- or inter-disciplinary), these fundamental cognitive system limits must be respected. Only so much foundational content can be read, remembered, understood, and processed. As cognitive science ambitiously brought together many component disciplines, it is not so surprising that different laboratory groups, different journals, and different departments chose different ways of bounding the overall expansion (e.g., being heavier in psychology like RPI, heavier in linguistics like JHU, or heavier in neuroscience like CEU; see their Fig. 2c). Further, since, in many senses, these sociological units compete with each other for resources in a relatively small pool (as will naturally be the case for new disciplines), specialization is what would be expected. For example, a department might tell potential doctoral candidates that they might not have as many top linguists as they do at JHU, but they instead are stronger in neuroscience). This a fundamental insight frequently applied in economic analysis of competition (e.g., Feldman & Audretsch, 1999; Grant, 1996; Hochberg, Mazzeo, & McDevitt, 2015). Such specialization might also allow each group to have a competitive advantage in

certain research topics, making more rapid progress as a result of unique access to outside talent pools, highly relevant disciplinary knowledge, and developed local expertise.

Looking from the perspective of an optimally designed discipline as a whole using systems biology concepts, one might argue that diversity at the department level is critically important for success. When every organism looks the same, critical flaws can be devastating to all of them. Blights wipe out crops across large geographical regions when there is a monoculture. For example, if every cognitive science department relied heavily on neuroscience, then heavy declines in funding for neuroscience would damage them all.

4. Conclusion: Where next?

Through critical analysis of analytic methods and assumed normative models of good science, I argue that it is not (yet) appropriate to call for the death of cognitive science. First, the bibliometric analyses need to be redone using a broader exploration of models and analytic techniques. Second, there remain social worlds in the form of conferences, journals, and training programs that fly under that flag to offer some basic proof-by-existence for the discipline of cognitive science. The analyses of Núñez at al. are persuasive in pointing to the high variability within the social worlds even if they are not persuasive in documenting its non-existence. At the very least, one could argue that cognitive science should rebrand to become a plural (cognitive sciences) in order to formally acknowledge this variability. Such rebranding might lead to further conceptual and empirical analysis of the advantages and disadvantages of such variability, leading (perhaps) into productive changes within the conference, training programs, and journals of cognitive science.

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