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What happened to cognitive science?

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Abstract:

More than half-century ago the "cognitive revolution", with the influential tenet “cognition is computation”, launched the investigation of the mind through a multidisciplinary endeavor —“cognitive science”. Despite significant diversity of views regarding its definition and intended scope, this new science, explicitly named in the singular, was meant to have a cohesive subject matter, complementary methods, and integrated theories. Multiple signs, however, suggest that over time the prospect of an integrated cohesive science did not materialize. Here, we investigate the status of the field in a data-informed manner, focusing on four indicators—two bibliometric and two socio-institutional. These indicators consistently show that the devised *multi*-disciplinary program failed to transition to a mature *inter*-disciplinary coherent field. Bibliometrically, the field has been largely subsumed by (cognitive) psychology, and educationally, it exhibits a striking lack of curricular consensus, raising questions about the future of the cognitive science enterprise.

The "cognitive revolution" of the 1950s and 1960s brought the exciting prospect of investigating "the mind" scientifically, in a well-integrated interdisciplinary field with a coherent subject matter, common research questions, complementary methods, and theoretical developments[1-6]. Motivated by the shared urge of overcoming the limitations of behaviorism that ruled mid-20th century psychology[2,5], and fueled by the emergence of the computer technology of the 1940s and 1950s, this revolution was largely driven by the tenet that "cognition is computation of representations" and the view that the mind is fundamentally a computational entity[7]. The enterprise led to the creation of a new field named "cognitive science".

Although from the outset, there was substantial diversity among the cognitive science community regarding the scope and aims of the field[2,6,8], a salient conceptualization of the field envisioned it as the product of fruitful interactions between six main disciplines — psychology, linguistics, artificial intelligence, anthropology, philosophy, and neuroscience. This multidisciplinary research program has been since iconically depicted as a regular hexagon [2,5,8-10] (Fig. 1A), which has continued to be emblematic of the field until today[11]. The new science was deliberately labeled in singular form, to reflect a strong commitment with achieving an integrated and cohesive research program. Crucially, "science" in cognitive science, has had a specific unifying connotation, not implied in other fields such as "computer science", "developmental science", or "data science". One of the most authoritative histories of the field named this promising new enterprise "the mind's new science"[2].

Over the decades, however— forty years since the creation of the journal *Cognitive Science* in 1977 and of the *Cognitive Science Society* in 1979— the field as a whole seems to have lost impetus, focus, and recognition. Contrary to enthusiastic initial predictions, after the creation of the first Ph.D.-granting cognitive science department at UCSD in 1986, only a handful of equivalent departments have been created since. Out of the 131 R1 research universities in the United States (i.e., with "highest research activity")[12], less than 15% of them have a program granting a Bachelor's degree in the field. Some, at best offer a "cognitive science track in psychology" (e.g., Harvard

University[13]), or offer a degree under a different name altogether despite covering significant overlapping content (e.g., "Symbolic Systems Program" at Stanford University[14]). Besides, the *Web of Science* database indexes journals with "cognitive science" in their name simply as "experimental psychology"[15]. Even the publisher of both journals of the *Cognitive Science Society* (*Cognitive Science: A Multidisciplinary Journal* and *Topics in Cognitive Science*) not only does not list cognitive science among its nearly 300 main subjects, but it does it simply under one of the 13 sub-categories of psychology: "cognitive psychology" (https://www.wiley.com/en-us/subjects; https://www.wiley.com/en-us/Cognitive+Science+A+Multidisciplinary+Journal-p-9780JRNL71158; https://www.wiley.com/en-us/Topics+in+Cognitive+Science-p-9780JRNL71172; retrieved August 3, 2018). Furthermore, bibliometrically, by the year 2000 the field's flagship journal *Cognitive Science* had decreased its interdisciplinarity, with the journal becoming barely distinguishable from journals in cognitive psychology[15-16]—a pattern given as example of failed interdisciplinary integration[17]. And, overall, by looking at how and by whom cognitive science is taught at universities and colleges, undergraduate curricula and faculty backgrounds give the impression that cognitive science has gradually turned its unified effort into an eclectic group of academic practices that no longer have clear common goals, research questions, or theories. Indeed, the label "cognitive scientist" today is often used as a catch-all designation to label (or self-label) scholars with a dizzying array of unrelated interests and theoretical orientations. Importantly, many universities and research institutions around the world today seem to be producing exciting and successful cross-disciplinary mind-related work in a non-normative manner, outside (or without the need) of "cognitive science".

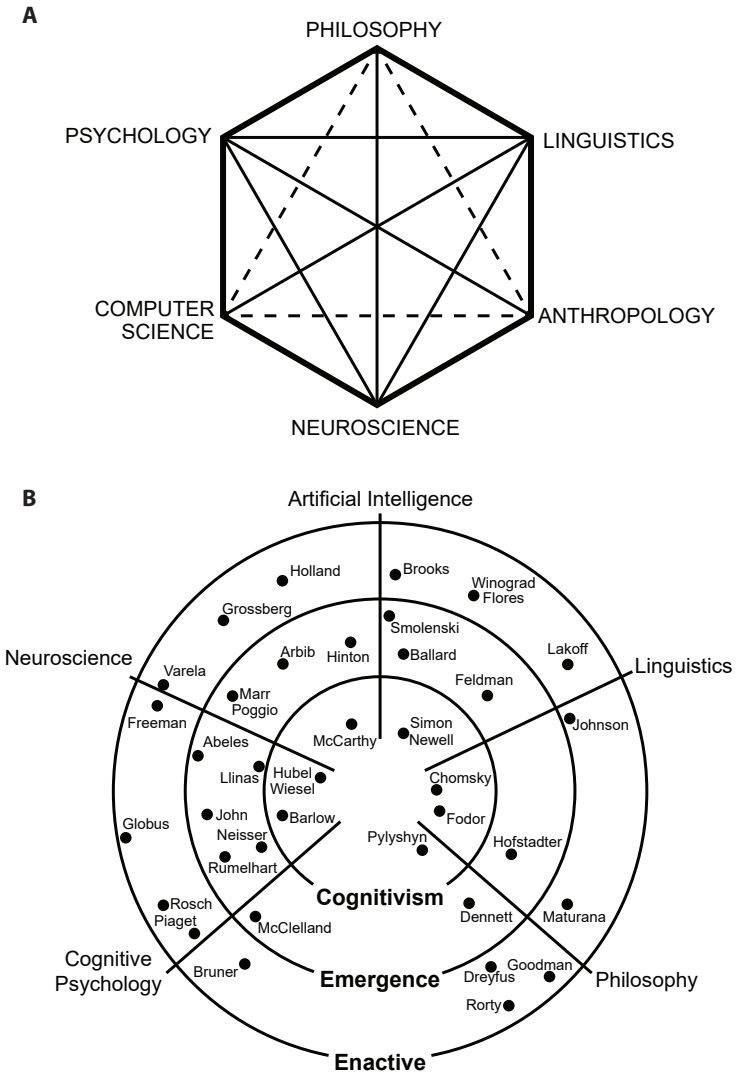

Figure 1. The multi-disciplinarity of cognitive science. (A) The "Cognitive Science Hexagon", redrawn from the original cover of the Sloan Foundation's 1978 State of the Art Report on Cognitive Science[8], and which has later being reproduced in many other venues[2,5,9-11]. It depicts a regular hexagon representing the six disciplines which are said to contribute to the constitution of the field of cognitive science. (B) A graphic representation of the diversity of views in the cognitive sciences published in 1991 by Varela, Thompson, and Rosch[21, p7]. The original caption reads: "A conceptual chart of the cognitive sciences today in the form of a polar map, with the contributing disciplines in the angular dimensions and different approaches in the radial axis."[21, p7]. Note that to capture the wide diversity of approaches the authors use the plural form for "cognitive sciences". Also, by that time the contributions of anthropology to the field had been rather minimal to have granted, in the authors' mind, an angular dimension for it in the chart (redrawn and adapted from references #21 and #39).

Given this picture—nearly half a century after the institutionalization of cognitive science— the natural question to ask is what happened to "cognitive science"? Does cognitive science (in the singular) still exist as a coherent academic field with a well-defined and cohesive interdisciplinary research program? If it does not — or if multiple "cognitive sciences" have emerged — how does the state of the field today compare to predictions made by early commentators and enthusiasts of the field? In this article we attempt to respond to these questions in a data-informed manner with on-the-ground facts. We examine four indicators: two bibliometric indicators that analyze the affiliation of authors in the journal *Cognitive Science* and the citation environment of this journal, and two socio-institutional indicators that analyze the doctoral training of current cognitive science faculty and the current undergraduate cognitive science curricula in North America.

The challenge of achieving interdisciplinary coherence: difficulties from the beginning

Cognitive science is a product of the 1950s in North America, when psychology, linguistics, and anthropology were redefining themselves, and computer science and neuroscience were emerging on the academic scene[5]. While working definitions of cognitive science vary widely, highly influential early proposals were built on the fundamental cornerstone that "thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on those structures"[18, p10]. As such, cognitive science has been defined as "the study of intelligence and intelligent systems, with particular reference to intelligent behavior as computation"[3, p1]. Defining the purview of the field, however, has been anything but simple. In his influential 1987 *Mind's New Science* Howard Gardner notes that, "since the term *cognitive science* first began to be bandied about in the early 1970s, dozens of scientists have attempted to define the nature and scope of the field"[2, pp5-6] (emphasis in original). While recognizing the diversity of views in the field, he characterized some

essential original features of the cognitive-scientific enterprise, where at the top we find[2, p6]:

1) "the belief that, in talking about human cognitive activities, it is necessary to speak about mental representations and to posit a level of analysis wholly separate from the biological or neurological, on the one hand, and the sociological or cultural, on the other."
2) "the faith that central to any understanding of the human mind is the electronic computer."
3) "the deliberate decision to de-emphasize certain factors … [including] the influence of affective factors or emotions, the contribution of historical and cultural factors, and the role of the background context in which particular actions or thoughts occur".

Many scholars today may not agree with these original tenets, but beyond the diversity of definitions that have been offered over the years, what can be retained is that cognitive science has had a strong commitment with the notion of "mental representation" and with the constitutive role played by the computer (and computation) in the development of the field's body of knowledge. These elements have constituted a central component of what philosopher of science Imre Lakatos called the "hard core" of a field's research program—basic tenets and conjectures that are not meant to be challenged or refuted if the research program is to be successful[19]. Thus, some have noted that cognitive science "pays particular attention to intelligent behaviour as computation and is thereby associated with machines that can compute."[20, pIX]; others, that in the field "an important pole is occupied by artificial intelligence—thus the computer model of the mind is a dominant aspect of the entire field."[21, pp4-5]; And others, that cognitive science holds general "assumptions that the mind is (1) an information processing system, (2) a representational device, and (3) (in some sense) a computer"[4, pXIII]. This general characterization is also found in more recent influential publications, such as Margaret Boden's 2006 monumental two-volume history of cognitive science: "The field would be better defined as the study of

'mind as machine' … More precisely, cognitive science is *the interdisciplinary study of mind, informed by theoretical concepts drawn from computer science and control theory*."[6, p12] (emphasis in original).

What concerns us here is that already by the 1970s serious difficulties had emerged regarding the question of how, based on the above foundational features, the contributing disciplines would mesh in a coherent manner. Referring to an important 1978 report involving the Sloan Foundation —which provided crucial funding for establishing cognitive science[8]—Gardner wrote that "… tensions about what the field is, who understands it, who threatens it, and in what direction it ought to go were encountered at every phase of the Sloan Foundation's involvement (and have continued to be to this day)"[2, p36]. And added: "the community-at-large adopted a distinctly negative view of the report. In fact, such virulent opposition was expressed by so many readers that, counter to original plans, the document was never published. … Moreover, there is as yet no agreed-upon research paradigm — no consensual set of assumptions or methods — and so cognitive scientists tend to project their own favorite paradigms onto the field as a whole. In view of these factors, it was probably not possible in 1978 to write a document that would have won the support of a majority of cognitive scientists"[2, p37].

In the 1980s and 1990s coherence and integration appeared even less achievable as dissatisfactions with the reductionistic initial tenets of the cognitive revolution (sometimes referred to as "cognitivism"[21], Fig. 1B), led to the emergence of new views, methods, and approaches that challenged the very foundational features mentioned above. For instance, inspired by the rich interconnectivity of the nervous system, "Connectionism" (also called "Emergence"[21], Fig. 1B) and "Parallel Distributed Processing"[22] challenged the basic assumption that the mind performed computations serially, and with it radically changed the essential notion of "mental representations"; "Situated cognition" posited that cognition does not exist in a vacuum and is fundamentally tied to background and context[23-26]; "Distributed cognition" argued that cognition does not simply reside in individual's heads but is essentially distributed

among agents and environments[27-28]; "Embodied cognition" advanced that cognition is inherently grounded in bodily features and does not work in terms of amodal representations[21, 29-34]; and "Enactive cognition" rejected all together the fundamental tenet that "mental representations" are essential for understanding cognition[21, 35-37] (Fig. 1B). With such fundamental theoretical challenges, raised at various levels, and the progressively diverging proposed courses of action that those challenges inspired, the prospect of a coherent and integrated interdisciplinary science of the mind became increasingly elusive. In Lakatos' terms these cumulative fundamental challenges were addressed to the "hard core" of the research program—a recipe for an unsuccessful research program. Thus, by the 1980s and 1990s it was common to read that in cognitive science "there is very little, if any, consensus concerning a set of more specific goals and metatheoretical assumptions that could define a coherent field of inquiry"[38, p16]; that cognitive science "is not yet established as a mature science … rather, it is really more of a loose affiliation of disciplines than a discipline of its own."[21, pp4-5]; or that "cognitive science is … a perspective, rather than a discipline in any conventional sense."[20, pIX]. The dispersion and multiplicity of theoretical views—some mutually inconsistent— that could already be observed by that time is captured by the chart in Figure 1B published by Francisco Varela and colleagues in 1991[21,39].

As has been attested by many scholars, there is no doubt that cognitive science has been *multi*-disciplinary from its birth[1,15,40-45]. Cooperation among disciplines, however, does not imply coherent *inter*-disciplinary integration[16] (See Box 1). In the 1980s Gardner made this clear with a sharp distinction between the prospective paths for a *weak* and a *strong* cognitive science. The former simply "calls for cooperation among the six member disciplines … [which] is quite possibly the norm today but scarcely warrants the label of an important new science."[2, pp389-390]. By contrast, "in a stronger, more gritty version of cognitive science, there will be gradual attenuation of disciplinary boundaries and loyalties. These will be replaced by a concerted effort by scientists committed to a representational account to model and explain the most crucial human cognitive functions."[2, p390]. It is the *strong* version that concerns us here, as the goal of the important new science of the mind was "to blend together into one

seamless Cognitive Science"[2, p389]— hence its singular form. This would manifest not only in its research activities but also in the formation of new generations of scholars via well-integrated academic programs and coherently designed curricula at both undergraduate and graduate levels.

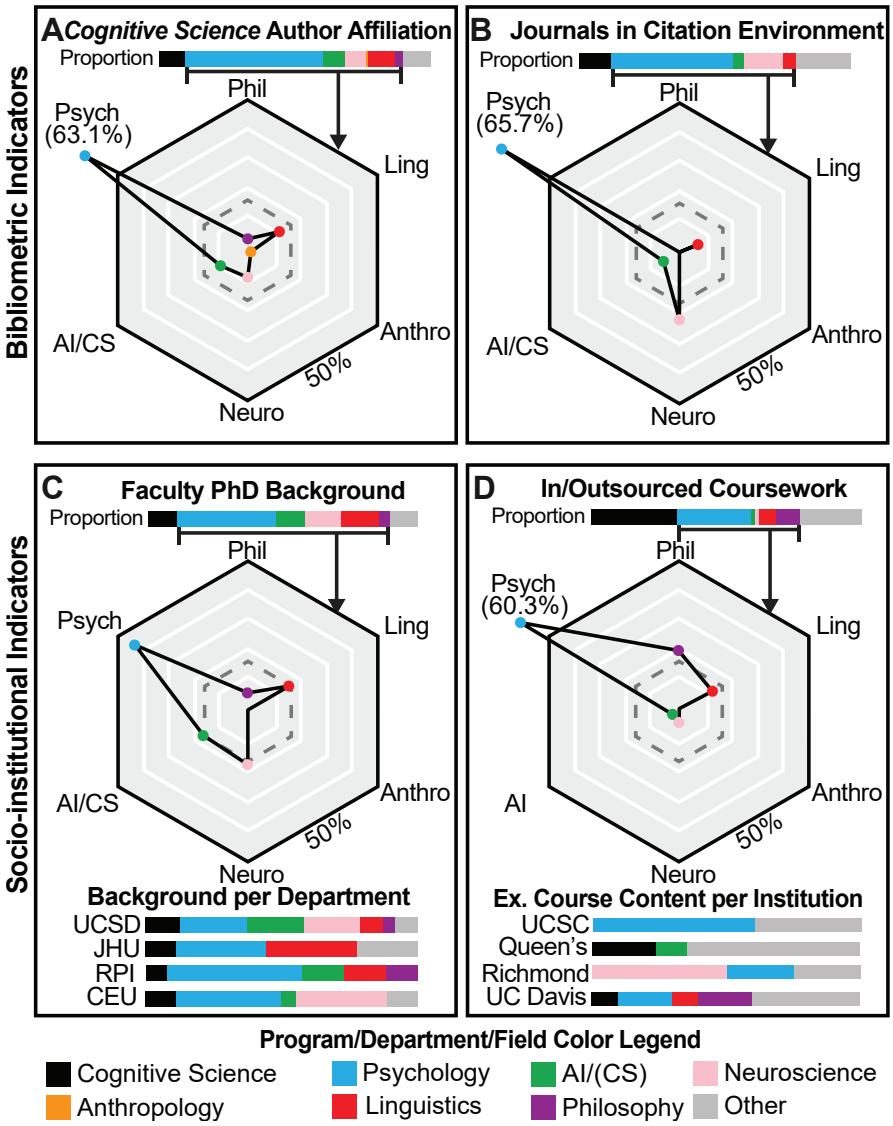

Figure 2. Four indicators of the status of cognitive science. The top two are bibliometric indicators, the bottom two are socio-institutional indicators. (A) The affiliation of authors in the journal *Cognitive*

Science, (B) the citation environment of this journal, (C) the doctoral training of current cognitive science faculty, and (D) the curriculum composition of current undergraduate cognitive science programs in North America. The top bars show the overall distribution of disciplinary contributions to each indicator. The hexagons represent the relative contribution from the six core disciplines. Moving outwards each hexagonal ring represents a 10% increment. A balanced distribution across core disciplines would follow the pattern indicated by segmented lines (i.e., ~16.6% each discipline), corresponding to the ideal "Cognitive Science Hexagon" (Fig. 1A). For data-gathering details see Supplementary Information. Taken together, these data systematically show that the prospect launched by the cognitive revolution more than half a century ago of a distinct, unified, and coherent interdisciplinary "seamless cognitive science"[2] did not materialize.

Four indicators—bibliometric and socio-institutional

Authors' affiliations in Cognitive Science

Building on the enthusiasm of the 1960s and 1970s, the journal *Cognitive Science* was launched in 1977 with a clear multidisciplinary perspective in mind[1], becoming the flagship journal of the *Cognitive Science Society* that would be founded two years later. Although the term "multidisciplinary" has appeared in the journal's subtitle from the beginning, the relative contribution from the various founding disciplines is less clear. In 1998, a report indicated that from the start —and consistently for the two decades that followed— the contributions to the journal had been consistently unbalanced, dominated by authors with affiliations in psychology and computer science[40]. Later, Gentner[9] observed further sharpening of the disciplinary distribution, with psychologists steadily increasing their presence by the 2000s. In this section we further investigate this question by looking in detail at all research articles and commentaries published in *Cognitive Science* after 2000.

We analyzed 1020 articles in total and tallied which disciplines were represented by all authors' affiliations (see details of data collection and processing in Supplementary Information). Overall, data show that after 2000 less than 10% of affiliations have come from departments or programs in cognitive science. Confirming Gentner's

observations[9], authors with psychology affiliations have continued to be consistently overrepresented among the core disciplines—by nearly 4 times their expected share (Fig. 2A, hexagon)— making up more than half of the affiliations in *Cognitive Science* (Fig. 2A top bar, see also Supplementary Figure 1). In stark contrast, anthropologists and philosophers are functionally absent in the journal, accounting for just 1% and 3% of the total affiliations, respectively. Interestingly, affiliations in neuroscience are also underrepresented in the journal (7%), despite our generous search criteria, which included generic terms such as "biology", "physiology", "brain", and "neuro". We also observe a small contribution from authors with affiliations in computer science (8.5%). This is particularly noteworthy given that our search included the term "artificial intelligence", one of the founding subfields of cognitive science. Overall, the disciplinary distribution of affiliations of *Cognitive Science* authors has been consistently characterized by strong lopsidedness over the years (Supplementary Figure 1).

Journal-journal citation patterns and environments —Scientometrics

An important indicator of the status of any research program or discipline is provided by bibliometric quantitative analysis of journal citation patterns and environments[17,46-50]— the subject matter of scientometrics[51-52]. While investigating the passage dynamics from multidisciplinarity to interdisciplinarity integration, Van den Besselaar and Heimeriks[16] studied the journal-journal communication network of several research fields, including cognitive science. Through a factor analysis on the cross-citation patterns of a group of journals with *Cognitive Science* as the entrance journal —covering the period 1982-1998, they found that the field's flagship journal had not developed a stable relational citation environment —a typical multidisciplinary pattern. Rather the environment had fluctuated between factors characterizing the areas of cognitive psychology and artificial intelligence. They noted that some fields may evolve from an unstable multidisciplinary state into more mature and coherent interdisciplinary modes of knowledge production (see Box 1)—which usually do not

depend on the traditional disciplines— but that this was not the case of cognitive science. These findings were corroborated in another study that performed factor analysis on data from the years 1988, 1998, and 2007, with the added observation that by 2007 *Cognitive Science*'s citation environment had radically changed as computer science and related fields became less central and the journal became part of the cognitive psychology factor[53]. Later, Leydesdorff and Goldstone[15] analyzed the knowledge base of the literature in *Cognitive Science* over three decades (1980-2011) using the citation pattern in the journal. For the 1980s and 1990s, their findings are consistent with previous reports[16] as they observed that in the 1980s *Cognitive Science* was in a phase of construction of the interdisciplinary space and in the 1990s it was developing an interdisciplinary orientation. Crucially, however, and concurring with the above results[53], they observed that by the 2000s *Cognitive Science* had not increased, but rather, had decreased its interdisciplinarity and the journal had been absorbed by cognitive psychology—a mono-disciplinary endeavor. These citation patterns have been characterized as a clear example of failed interdisciplinary integration[17]: emergence of multidisciplinarity, followed by unstable development and eventual disappearance[53].

Here, we extend the above research and look at the citation environments in *Cognitive Science* for the years 2000, 2007, and 2014. Retrieving data from the *Journal Citation Reports*, and following established scientometric methods[16,50], we performed principal component analyses on the covariance matrices of *Cognitive Science*'s outgoing and incoming citation matrices (details in Supplementary Information) and submitted them to hierarchical clustering. These matrices provide valuable and dynamic information about the knowledge base of the journal (outgoing citations) and the audience of the journal (incoming citations). Results, rendered as dendrograms (Fig. 3 and Supplementary Figure 2, for outgoing citing and incoming cited data, respectively), are consistent with the earlier findings described above. In all three years the journal's citation environment shows a complete lack of anthropology and philosophy journals, a weak presence of neuroscience, and an overrepresentation of psychology journals. Moreover, across the analyzed period, the number of journals in the citation

environment is reduced by 23%. This reduction is not uniform; the environment becomes less diverse, as computer science and other miscellaneous journals are no longer present. Figure 2B shows the disciplinary contribution to the citation environment for the year 2014 (see Supplementary Table 3 for details). Crucially, in both cases, outgoing citations and incoming citations the multiple clusters observed in 2000 and 2007 are considerably reduced and more clearly formed by 2014 (Fig. 3 and Supplementary Figure 2; Supplementary Figure 3), with a solid presence of *Cognitive Science* in a cognitive/experimental psychology cluster. Corresponding to each dendrogram in Figs. 3 and Supplementary Figure 2 there is a bar graph showing, respectively, the percentages of *Cognitive Science*'s citations given to/received from each journal in the environment for a given year. They confirm that by 2014 there is a solid overrepresentation of psychology, tighter sub-communities within *Cognitive Science*'s citation environment, and a decline in interdisciplinarity in both the knowledge base and audience of cognitive science's literature: the highest volume of citations goes to, and are received from the large psychology clusters.

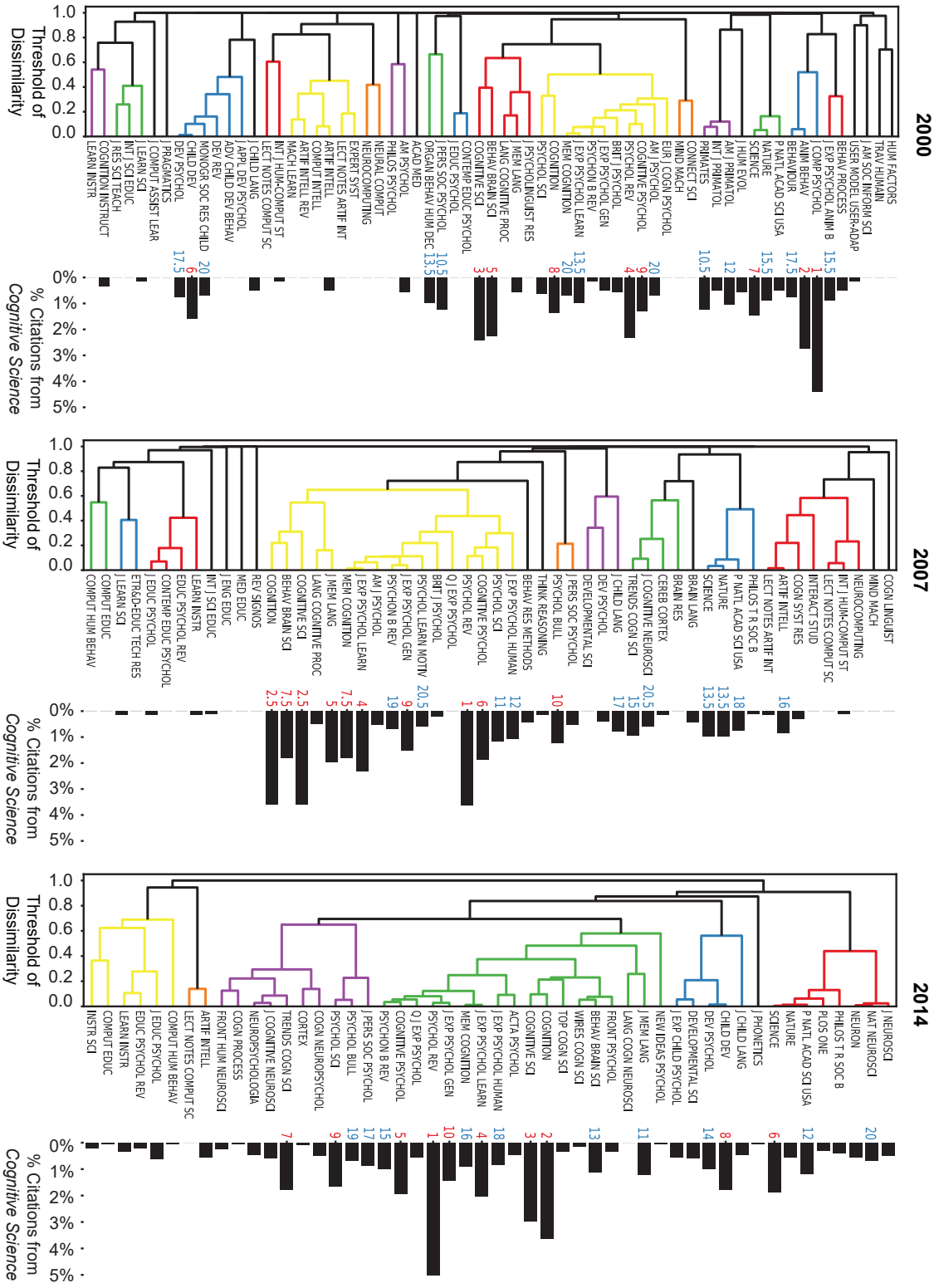

Figure 3. The citation environment of the journal *Cognitive Science* for the years 2000, 2007, and 2014. For each of the three years the environment shows a dominance of psychology journals, a nearly

complete lack of anthropology and philosophy journals, and a weak presence of neuroscience journals. Over the years the number of journals in the citation environment gets reduced and becomes less diverse. The figure shows dendrograms (hierarchical clustering) for these years based on citing data (reflecting the knowledge base of the journal) from the *Journal Citation Reports*. Journals that are clustered together show similar citation patterns. To facilitate visualization clusters are colored (here with a dissimilarity threshold set at 0.69; colors themselves have no meaning). By 2014 the journals are clustered in a much more defined manner than in the previous years (Supplementary Figure 3A), and are primarily about psychology. The bar graphs to the right of each dendrogram show the percentages of total *Cognitive Science*'s outgoing citations for the given year that go to each of the journals in the environment. The ranks of the 20 journals most cited by *Cognitive Science* that year appear next to the longest bars (red: 1st-10th; blue: 11th-20th). By 2014 the highest volume of citations solidly goes to the dominant psychology cluster, to which *Cognitive Science* belongs. The results confirm both the overrepresentation and siloing of psychology, and the decline in interdisciplinarity in the knowledge base of cognitive science's literature. (A similar pattern is observed for incoming citations (audience of the journal); See Supplementary Figures 2 and 3B).

The doctoral training of cognitive science's faculty today

For an academic field to function with a self-sustaining research program, an infrastructure of researchers and teaching faculty able to train future generations is critical. In cognitive science, early visionaries predicted that this infrastructure would originally be built in the form of departments and programs led by faculty originally trained in the six founding disciplines represented on the cognitive science hexagon (Fig. 1A). Initially dominated by faculty with backgrounds well-distributed through the hexagon, these programs would eventually transcend the disciplinary boundaries of their founders as a new generation of scientists trained from the onset to engage in a *strong* disciplinary version of cognitive science takes the reins[2]. A glimpse at faculty educational backgrounds in current Ph.D.-granting departments of cognitive science provides evidence that this prediction has not been fulfilled.

We collated (April 2018) the publicly available educational histories of all active faculty in the four departments of cognitive science that grant a Ph.D. degree: Johns Hopkins University (JHU), Renssaeler Polytechnic Institute (RPI), the University of

California, San Diego (UCSD), and the Central European University in Budapest (CEU). To our knowledge, these are the only departments of cognitive science as of 2018 (not named in plural and/or in conjunction with "brain", "psychology", etc.), which maintain a full-time faculty and offer a doctoral level degree in cognitive science (details in Supplementary Information). Data reveal that faculty who received Ph.D. training explicitly in cognitive science remain a decided minority in all departments (<10% of total of 55 faculty; Fig. 2C black in top bar). If a gradual erosion of disciplinary boundaries has simply occurred much slower than anticipated, we would still expect a relatively homogenous distribution of Ph.D. backgrounds of the remainder of the faculty. But this is not what we observe (Fig. 2C, hexagon). The most consistent feature across departments is the overrepresentation of faculty with training in psychology and the complete lack of faculty with a background in anthropology. Moreover, the distribution of faculty with backgrounds in neuroscience, linguistics and computer science vary drastically across the departments with each constituting as little as 0% in one department and more than 20% in another (Fig. 2C, bottom bars). In no department do faculty represent the interdisciplinary distribution envisioned in the 1970s and 1980s[2].

Cognitive science curricula across universities in North America

Undergraduate curricula reflect disciplinary views and values, and form the foundation for future researchers and practitioners in established fields[54-55]: A curriculum is a constitutive part of the definition of a field. Therefore, a crucial indicator for assessing the current state of cognitive science is the training undergraduate students receive in the field. If a *strong* cognitive science currently exists as a coherent field, we would expect to see that reflected in the curricula of programs that offer a degree in cognitive science. Specifically, we would expect that undergraduates who are granted this degree receive the majority of their core training through cognitive science courses. Alternatively, if a weaker version of cognitive science is the norm we would at least

expect to see all six of the main disciplines reflected in systematic and balanced ways in the curricula of degree-granting institutions.

We examined the coursework requirements of the 33 North American institutes of higher education that to our knowledge grant Bachelor's degrees in cognitive science (this excluded institutions that only offer a "minor" or just issue a "certificate"; see Supplementary Information for details). The institutions were gathered from lists available as of May 2018 from *The College Board* (https://www.collegeboard.org) and the *Cognitive Science Society* "Academic Programs in Cognitive Science" webpage[56]. For each university, we accessed the degree requirements posted on the program's website and examined the core requirements for the major — the courses that all undergraduate cognitive science majors need to take to receive the cognitive science degree. Specifically, for each institution we counted the number of courses in cognitive science and in each of the core disciplines that all cognitive science majors would be exposed to. To capture different aspects of the curriculum implementation, we did this in terms of content and by the department which hosted each course (details in Supplementary Information). From this, we determined the proportion of the total core curriculum occupied by each field.

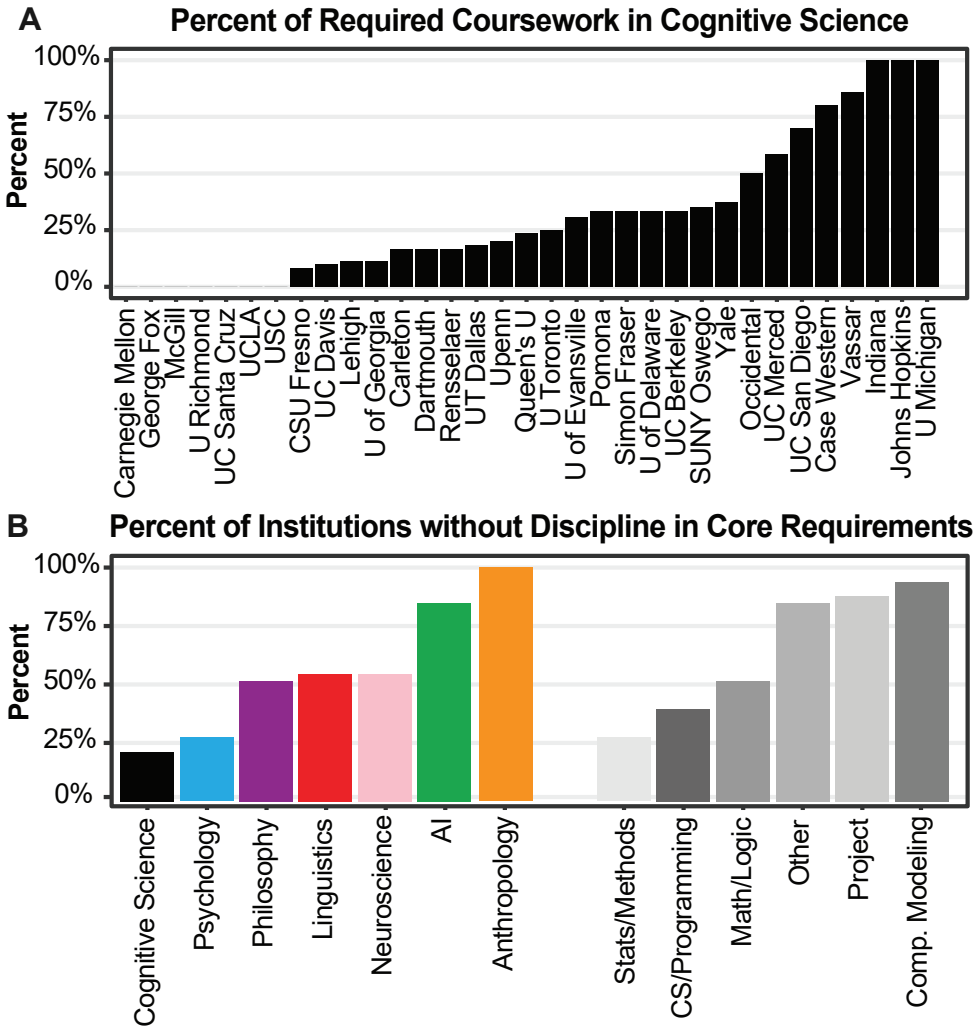

Figure 4. The current undergraduate cognitive science curriculum in North America. (A) Percent of required coursework per university/program offering a Bachelor's degree in cognitive science that is explicitly about cognitive science (e.g., either listed as "COGS XXX" course, or mentioning "cognitive science" in the title while being offered in other departments). Only 8 institutions (24%) require more than 50% of coursework to be explicitly about cognitive science. Strikingly, 7 schools (21%) require no explicit cognitive science course to obtain the degree in this field. Overall, 18 institutions (55%) require only 25% or less of the courses to be about cognitive science. (B) Percent of schools that in the core requirements do not include courses in the listed disciplines. No school includes anthropology courses in the core requirements, and 21% of schools do not have cognitive science in the core requirements. No field is systematically present in the core requirements of schools offering a Bachelor's degree in cognitive science. Indeed, no field is present in more than 80% of these schools.

Contrary to what would be expected of a distinct unified field— 36 years after the initial granting of an undergraduate degree in cognitive science (Vassar College, 1982[57])— we found that on average only 32% of the core material that cognitive science majors are exposed to is in cognitive science (Fig. 2D, black in top bar; for details see Supplementary Figure 4). Strikingly, we found seven universities in which students can receive a degree in cognitive science without ever taking a single course explicitly labeled as cognitive science (Fig. 4A). Thus, at the majority of institutions, students receive most of their core training in fields outside of cognitive science, through courses that are outsourced to other departments. These outsourced requirements indicate two things. First, there is a markedly uneven distribution of required coursework across the six main disciplines (Fig. 2D, hexagon). The majority of the core curriculum comes from psychology, with most students receiving significantly less instruction in linguistics, philosophy, and neuroscience. Notably, we didn't find a single institution that required cognitive science majors to take a course in anthropology (although several programs included optional anthropology courses). Second, we observe a striking lack of coherence in degree requirements across institutions (see examples in Fig. 2D, bottom bars). For instance, most of the core curriculum at the University of California, Santa Cruz (UCSC) comes from psychology, while at Queen's University the only founding discipline represented in the curriculum is artificial intelligence (which, meanwhile, is nowhere in the core requirements at the other example institutions). In fact, we were unable to identify a single content area that was common to all cognitive science core requirements (Fig. 4B). The curricular data from North American universities do not support the existence of a coherent and unified "seamless cognitive science"[2].

Discussion

What happened to cognitive science? All indicators analyzed here—bibliometric and socio-institutional—point systematically in the same direction. The prospect launched by the cognitive revolution of a unified and coherent interdisciplinary "seamless

cognitive science"[2] did not materialize. Ph.D.-granting departments have never been more than a handful and today, contrary to predictions, their faculty is still primarily trained in the traditional founding disciplines and is markedly unevenly distributed. This distinguishes cognitive science from mature fields such as mathematics, psychology, philosophy, computer science, or linguistics, where most faculty normally hold doctoral degrees in the corresponding field. Tellingly, undergraduate programs in cognitive science are far from showing a coherent and consistent curriculum. Our Ph.D. background and undergraduate curricular data appear to largely concur with, and validate scientometric methods for investigating the development of scientific disciplines and research programs[15-16,53]. Indeed. bibliometrically, affiliation and publication patterns in the flagship journal of the *Cognitive Science Society* show that the field has been essentially absorbed by psychology, and the journal does not directly contribute to advances in brain research, or to much anthropology or philosophy (if at all). In general, (cognitive) neuroscientists choose to publish outside of cognitive science journals.

The cognitive science enterprise faced, from the start, substantial challenges to find integration. And over the decades, things became ever more elusive. Steady challenges to the fundamental tenets of the field[21,22,26,35-36,58-60], failures in classic artificial intelligence handling common sense and everyday language[61-63], major difficulties in integrating cultural variation and anthropology[64-69], as well as developments in brain research[70-71], genomics[72-73], and evolutionary sciences[68,74-75] seem to have gradually turned the enthusiastic initial common effort into a rather miscellaneous collection of academic practices that no longer share common goals and paradigms. Indeed, in scientometrics[51-52], unlike successful cases of interdisciplinary integration such as bio-chemistry, cognitive science has been referred to as the textbook case of failed interdisciplinarity and disappearance[17,53].

This failed integration has also been aggravated by the fact that over the years the term "cognitive" has become highly polysemous and theoretically loaded, even in inconsistent ways. For instance, "cognitive" in "cognitive psychology" primarily

denotes information-processing psychology, following influential work in the 1960s[76] that saw cognitive science as essentially the marriage between psychology and artificial intelligence[77-78] in which neuroscience and the study of culture played virtually no role. Thus, "cognitive" psychology doesn't just designate a sub-field of psychology that studies cognition and intelligence. Rather, it usually refers to a specific theoretical approach and research program in psychology[76-79]. As a consequence, research on thought, language, and reasoning based on, say, the work of Jean Piaget[80-83] or Lev Vygotsky[84-85]—who studied the psychology of thought, reasoning, and language— is normally not considered "cognitive psychology". Indeed, in recent cognitive psychology textbooks the work of these great pioneers is not even mentioned[79]. When attached to "linguistics", "cognitive" denotes an entirely different thing. "Cognitive linguistics" refers to a specific field that emerged in the 1980s[86-92] as an explicit alternative to Chomskian linguistics[93-97], defending the view that language is not a special-purpose module, but is governed by general principles of cognition and conceptualization[98-99]. Thus, the term "cognitive" in cognitive linguistics designates a school in linguistics that it is fundamentally opposed to—and inconsistent with—Chomskian linguistics, which, with its formal treatment of language had appealed to the computer scientists, anti-behaviorist psychologists, and analytic philosophers of the 1950s and earned it a privileged founding role in cognitive science in the first place[2,5].

Another founding role was played by psychology, which according to previous findings[8,15-16,53] and the indicators analyzed here, has become decidedly overrepresented in cognitive science. But rather than being a "conquest"[9] of the field, there seems to be a progressive disinterest on the part of other disciplines in investigating the mind in terms of the computationalist-representationalist tenets defined by the cognitive revolution. The recent announcement for the *Cognitive Science Society* 2017 meeting crystallizes this situation today: "computation can serve as the foundational theory of how people actively process information in service of control and decision making … greater effort must be made to connect cognitive science theories to computational foundations"[100]— a framing that hardly accommodates

anthropologists[65,68] or biologists studying real-world living systems[36,60,101]. Thus, psychology appears to be overrepresented in cognitive science because via its "cognitive psychology" strand it offers the best fit with the foundational tenets of the cognitive revolution— cognitive science's original "hard core". Scientometrics data support this interpretation: since the 2000s *Cognitive Science* has seen its interdisciplinarity decrease[15] and it has begun to reintegrate itself into cognitive psychology[15-16,53]—an endeavor far from its original interdisciplinary goal.

Overall, the data we have presented show that cognitive science has failed to become an integrated and cohesive interdisciplinary field. George Miller, one of the founding fathers of cognitive science[102] seems to have reached a similar conclusion sixteen years ago. As he put it: "Some veterans of those [early] days question whether the [cognitive revolution] program was successful, and whether there really is something now that we can call 'cognitive science'. For myself, I prefer to speak of the cognitive sciences, in the plural"[5, p144]. Indeed, many scholars have expressed similar views for years[10,20-21]. In *What is Cognitive Science?* Barbara Von Eckardt stated that "it is possible to be skeptical about whether cognitive science exists as a coherent intellectual enterprise. Perhaps there is no such thing as cognitive science, really. Perhaps there are just cognitive *sciences*"[10, p1] (emphasis in original). Indeed, organizations seem to have quietly grasped the trend by, for instance, titling high-impact publication venues in the plural (e.g., the journal "Trends in Cognitive Sciences" (https://www.journals.elsevier.com/trends-in-cognitive-sciences), "The MIT Encyclopedia of the Cognitive Sciences"[103], PNAS' "Psychological and Cognitive Sciences" subcategory (https://www.pnas.org/psychological_cognitive_sciences)), and universities by officially naming their departments in the plural and/or in conjunction with other fields: "Brain and Cognitive Sciences" (e.g., MIT (https://bcs.mit.edu), University of Rochester (http://www.sas.rochester.edu/bcs/), Seoul National University, Korea (http://bcs.snu.ac.kr/sub1_1.php?ckattempt=1)); "Cognitive, Linguistic and Psychological Sciences" (e.g., Brown University (https://www.brown.edu/academics/cognitive-linguistic-psychological-sciences/home)); "Department of Human Informatics and Cognitive Sciences" (Waseda

University, Japan (https://waseda.pure.elsevier.com/en/organisations/department-of-human-informatics-and-cognitive-sciences/persons/)); "Cognitive and Information Sciences" (UC Merced (http://cogsci.ucmerced.edu/graduate-group/)); or simply "Cognitive Sciences" but choosing to grant their doctoral degree in "Psychology" (UC Irvine (http://catalogue.uci.edu/schoolofsocialsciences/departmentofcognitivesciences/#graduatetext)). The plural does seem to more accurately capture the situation today, as it did at the time of George Miller's impressions, but that was certainly not the goal of the cognitive revolution— *the mind's new science*. The plural simply reverts to Gardner's *weak* version, which calls for cooperation among disciplines "but scarcely warrants the label of an important new science."[2, pp389-390].

In sum, following Imre Lakatos cognitive science appears to have failed to generate a "successful research program"[19, p48]. In his terms, the "hard core" of a successful research program remains largely "irrefutable"; its basic tenets and conjectures stay unchallenged, "tenaciously protected from refutation by a vast 'protective belt' of auxiliary hypotheses"[19, p4]. Cognitive science with its (arguably reductionistic) fundamental features, has seen its "hard core" progressively challenged, and to some extent refuted, from within by various schools and approaches, and has failed to build a robust "protective belt" (of "auxiliary hypotheses") around a coherent "hard core". In Lakatos' terms, this has led not to a progressive problemshift but to a "degenerating problemshift" resulting in an unsuccessful research program[19, p48]. This interpretation is supported by scientometrics data[16-17], which show that in the dynamics of academic and scientific evolution, cognitive science failed to move from a collection of enthusiastic *multi*-disciplinary efforts to an integrated coherent *inter*-disciplinary field. But, importantly, it is supported also by the socio-institutional data analyzed here that show that there is a substantial lack of consensus across universities and colleges on what the curriculum is or should be when it comes to grant a degree in "cognitive science". Acknowledging this reality has research, educational, and professional policy-making implications: In the end, what exactly is the subject matter of this field? If a degree in "cognitive science" is to be granted, what contents should be taught, and by

whom? What should employers expect to be the knowledge and skills of applicants with a "cognitive science" degree? To what extent is the training in "cognitive science" necessary for forming the new generation of scientists of the mind?

The cognitive revolution was largely a normative anti-behaviorism counter-revolution[5], whose inspiring legacy was to bring to the fore the importance of cross-disciplinary collaboration. But today, the exploding and exciting contemporary scientific study of the mind appears to have left the cognitive revolution behind, in a gradual, non-normative, and non-revolutionary manner, for the moment not settling on any particular paradigm or research program. It is up to the future generations of scholars to figure out how, in the post-cognitive revolution era, to best proceed with the ever-fascinating enterprise of understanding the multiple and diverse dimensions of the mind.

Box 1 — Multidisciplinarity vs. interdisciplinarity

When referring to the collaboration and exchange between academic disciplines, the terms crossdisciplinarity, pluridisciplinarity, multidisciplinarity, interdisciplinarity, and transdiscipilnarity are commonly used. These terms, however, are often ambiguously defined and employed interchangeably[104]. Here, for the purposes of this article we mainly use two of these terms— multidisciplinarity and interdisciplinarity—which, respectively, capture the distinction by Gardner[2] between weak and strong cognitive science.

Multidisciplinarity "draws on knowledge from different disciplines but stays within their boundaries"[104, p351]. In multidisciplinary endeavors "the subject under study is approached from different angles, using different disciplinary perspectives. However, neither the theoretical perspectives nor the findings of the various disciplines are

integrated in the end"[16, p706]. In contrast, interdisciplinarity "analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole"[103, p351]. Interdisciplinary research "creates its own theoretical, conceptual and methodological identity. Consequently, the results of an interdisciplinary study … are more coherent, and integrated"[16, p706]. The corresponding prefixes "multi" (many) and "inter" (between) grasp the essence of the difference between the two concepts: while multidisciplinary simply refers to a collection (of disciplines) with an additive effect, interdisciplinarity refers to the cohesive interaction between them.

Multidisciplinary endeavors may develop into interdisciplinary ones, but since the latter demands a more sophisticated level of integration the potential passage from one to the other is non-trivial. The disciplinary, multidisciplinary, and interdisciplinary dynamics of research fields over time has been studied in scientometrics via bibliometric indicators[16-17,50]. An important finding in this area is that multidisciplinary fields are dominated by the traditional disciplines in the collaborative environment and tend to depend on them (e.g., psychology, in the case cognitive science[15-16]. Interdisciplinary fields, on the contrary, present modes of knowledge production that tend not to depend on the traditional disciplines, and exhibit a communication system that is similar to the patterns of (mono) disciplinary fields[16]. According to these definitions, and to scientometric findings, cognitive science started as a multidisciplinary endeavor (equivalent to Gardner's weak version[2]), but over the decades did not achieve interdisciplinarity (Gardner's strong version[2])— as an integrated coherent "one seamless Cognitive Science"[2, p389].

Data availability

The datasets generated in this study can be found on GitHub (https://github.com/rdgao/WH2CogSci) and FigShare (doi: 10.6084/m9.figshare.7973372). They are openly available and free for use, with proper attribution.

Code availability

The code used for analysis and draft figure generation, can be found on GitHub (https://github.com/rdgao/WH2CogSci) and FigShare (doi: 10.6084/m9.figshare.7973372). It is openly available and free for use, with proper attribution.

References

1. Collins, A. (1977). Why cognitive science. *Cognitive Science*, 1, 1-2.
2. Gardner, H. (1987*). The Mind's New Science: A History of the Cognitive Revolution*. New York: Basic Books.
3. Simon, H. & Kaplan, C.A. (1993). Foundations of Cognitive Science. In M.I. Posner, M.I. (Ed.). *Foundations of Cognitive Science* (pp. 1-47). Cambridge MA: MIT Press.
4. Bechtel, W. & Graham, G. (Eds.) (1998). *A Companion to Cognitive Science* (Volume 63 of Blackwell Companions to Philosophy). Malden MA: Blackwell Publishers.
5. Miller, G. (2003). The cognitive revolution: a historical perspective. *Trends in Cognitive Sciences*, 7(3), 141-144.
6. Boden, M. (2006). *Mind as Machine: A History of Cognitive Science* (Vols. 1&2). Oxford: Oxford University Press.
7. Posner, M.I. (Ed.) (1993). *Foundations of Cognitive Science*. Cambridge MA: MIT Press.
8. Sloan Foundation (1978). Cognitive Science, 1978. Report of the State of the Art Committee. New York. http://csjarchive.cogsci.rpi.edu/misc/
9. Gentner, D. (2010). Psychology in Cognitive Science: 1978–2038. *Topics in Cognitive Science*, 2, 328-344.
10. Von Eckardt, B. (1993). *What is Cognitive Science?* Cambridge MA: MIT Press.
11. Wikipedia, Cognitive Science (retrieved April 26, 2019)

https://en.wikipedia.org/wiki/Cognitive_science

12. Carnegie Classification of Institutions of Higher Education. Doctoral Universities: Highest Research Activity (retrieved February 26, 2019). http://carnegieclassifications.iu.edu/lookup/srp.php?clq=%7B%22basic2005_ids%22%3A%2215%22%7D
13. Harvard University, Psychology Undergraduate Program (retrieved February 27, 2019) https://undergrad.psychology.fas.harvard.edu/mbb
14. Stanford University. Symbolic Systems (retrieved February 27, 2019) https://symsys.stanford.edu/
15. Leydesdorff, L., & Goldstone, R. L. (2014). Interdisciplinarity at the journal and specialty level: The changing knowledge bases of the journal Cognitive Science. *Journal of the Association for Information Science and Technology*, 65(1), 164-177.
16. Van den Besselaar, P., & Heimeriks, G. (2001). Disciplinary, multidisciplinary, interdisciplinary: Concepts and indicators. In M. Davis & C.S. Wilson (eds.) *Proceedings of the 8th International Conference on Scientometrics & Informetrics* (ISSI) (pp. 705-716). Sydney, Australia: University of New South Wales.
17. Vugteveen, P., Lenders, R., & Van den Besselaar, P. (2014). The dynamics of interdisciplinary research fields: the case of river science. Scientometrics, 100(1), 73-96.
18. Thagard, P. (2005). *Mind: Introduction to Cognitive Science*. Cambridge MA: MIT Press.
19. Lakatos, I. (1978). *The Methodology of Scientific Research Programmes*. Vol. I. Cambridge Univ. Press.
20. Sheehy, N. & Chapman, A.J. (Eds.). (1995). *Cognitive Science*, Volume I. New York: University Press.
21. Varela, F., Thompson, E., and Rosch, E. (1991). *The Embodied Mind: Cognitive Science and Human Experience*. MIT Press.

22. Rumelhart, D.E., McClelland, J.L. & PDP Group (1987). *Parallel Distributed Processing Vol. 1*. Cambridge MA: MIT Press.
23. Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge UK; Cambridge University Press.
24. Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher*, *18*(1), 32-42.
25. Clancey, W. J. (1997). *Situated cognition: On human knowledge and computer representations*. Cambridge UK: Cambridge University Press.
26. Robbins, P., & Aydede, M. (Eds.). (2009). *The Cambridge handbook of situated cognition*. Cambridge: Cambridge University Press.
27. Cole, M., & Engeström, Y. (1993). A cultural-historical approach to distributed cognition. In G. Salomon (Ed.) *Distributed cognitions: Psychological and educational considerations* (1-46). Cambridge UK: Cambridge Univ. Press.
28. Hutchins, E. (1995). *Cognition in the Wild*. Cambridge MA: MIT Press.
29. Clark, A. (1999). An embodied cognitive science?. *Trends in cognitive sciences*, 3(9), 345-351.
30. Thelen, E., Schöner, G., Scheier, C., & Smith, L. B. (2001). The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioral and brain sciences*, 24(1), 1-34.
31. Wilson, M. (2002). Six views of embodied cognition. *Psychonomic bulletin & review*, 9(4), 625-636.
32. Pfeifer, R., Lungarella, M., Iida, F. (2007). Self-organization, embodiment, and biologically inspired robotics. *Science*, *318*, 1088-1093.
33. Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617-645.
34. Calvo, P., & Gomila, T. (Eds.). (2008). *Handbook of cognitive science: An embodied approach*. San Diego CA: Elsevier.
35. Freeman, W. & Skarda, Ch. (1985). Spatial EEG patterns, non-linear dynamics and perception: The neo-Sherringtonian view. *Brain Research Reviews*, 10, 147-175.

36. Freeman, W., & Skarda, Ch. (1990). Representations: Who needs them? In J.L. McGaugh JL, Weinberger NM, Lynch G (eds.), *Third Conference, Brain Organization and Memory: Cells, Systems and Circuits* (pp. 375-380). New York, Oxford, Guilford Press.

37. Stewart, J., Gapenne, O., & di Paolo, E. (2010). *Enaction: Toward a New Paradigm for Cognitive Science*. Cambridge MA: MIT Press.

38. Miller, J.R., Polson, P.G., & Kintsch, W. (1984). Problems of methodology in cognitive science. In W. Kintsch, J.R. Miller, & P.G. Polson (Eds.), *Methods and Tactics in Cognitive Science* (pp. 1-18). Hillsdale NJ: Erlbaum.

39. Varela, F. (1989). *Connaître les sciences cognitives: tendances et perspectives*. Paris: Seuil.

40. Schunn, Ch., Crowley, K., & Okada, T. (1998). The growth of multidisciplinarity in the Cognitive Science Society. *Cognitive Science*, 22(1), 107-130.

41. Von Eckardt, B. (2001). Multidisciplinarity and cognitive science. *Cognitive Science*, 25, 453-470.

42. Derry, S.J., Schunn, C.D., & Gernsbacher, M.A. (Eds.). (2005). *Interdisciplinary collaboration: An emerging cognitive science*. Mahway, NJ: Erlbaum.

43. Thagard, P. (2005). Being interdisciplinary: Trading zones in cognitive science. In S. J. Derry, C. D. Schunn & M. A. Gernsbacher (Eds.), *Interdisciplinary collaboration: An emerging cognitive science* (pp. 317-339). Mahway, NJ: Erlbaum.

44. Goldstone, R., & Leydesdorff, L. (2006). The Import and Export of Cognitive Science. *Cognitive Science*, 30(6), 983-993.

45. Bergmann, T., Dale, R., Sattari, N., Heit, E., & Bhat, H. S. (2017). The interdisciplinarity of collaborations in Cognitive Science. *Cognitive Science*, 41(5), 1412-1418.

46. Doreian, P., & Fararo, T. J. (1985). Structural equivalence in a journal network. *Journal of the American Society for Information Science*, 36(1), 28-37.

47. Borgman, C. L., & Rice, R. E. (1992). The convergence of information science and communication: A bibliometric analysis. *Journal of the American Society for Information Science*, 43(6), 397-411.

48. Tijssen, R. J. (1992). *Cartography of science: Scientometric mapping with multidimensional scaling methods*. Leiden: DSWO Press.
49. Leydesdorff, L., & Cozzens, S. (1993). The delineation of specialties in terms of journals using the dynamic journal set of the SCI. *Scientometrics*, 26(1), 135-156.
50. Van den Besselaar, P., & Leydesdorff, L. (1996). Mapping change in scientific specialties: A scientometric reconstruction of the development of artificial intelligence. *Journal of the American Society for Information Science*, 47(6), 415-436.
51. Van Raan, A. (1997). Scientometrics: State-of-the-art. *Scientometrics*, 38(1), 205-218.
52. Mingers, J., & Leydesdorff, L. (2015). A review of theory and practice in scientometrics. *European Journal of Operational Research*, 246(1), 1-19.
53. Van den Besselaar, P. (2018). Interdisciplinary and disciplinary identities: towards a theory of forms of knowledge change. www.biorxiv.org, DOI: https://doi.org/10.1101/603449
54. Ratcliff, J. L. (1997). What is a curriculum and what should it be. In J.G. Gaff & J.L. Ratcliff (Eds.) *Handbook of the undergraduate curriculum: A comprehensive guide to purposes, structures, practices, and change* (pp. 5-29). San Francisco CA: Jossey-Bass.
55. Gaff, J. G., & Ratcliff, J. L. (Eds.). (1997). *Handbook of the Undergraduate Curriculum: A Comprehensive Guide to the Purposes, Structures, Practices, and Change*. San Francisco, CA: Jossey-Bass.
56. Cognitive Science Society, "Academic Programs in Cognitive Science" (Retrieved May 14, 2018). http://www.cognitivesciencesociety.org/studying/
57. Vassar College, Cognitive Science Department (Retrieved September 6, 2018). https://cogsci.vassar.edu/about/
58. Dreyfus, H. (1972). *What Computers Can't Do: The Limits of Artificial Intelligence*. New York: Harper & Row.

59. Searle, J. (1980). Minds, brains, and programs. *Behavioral and Brain Sciences*, 3, 417-424.

60. Maturana, H. & Varela, F. (1987*). The Tree of Knowledge: The Biological Roots of Human Understanding*. Boston: New Science Library.

61. Winograd, T. (1972). Understanding Natural Language. *Cognitive Psychology*, 3, 1-191.

62. Winograd, T. (1980). What does it mean to understand language? *Cognitive Science*, 4, 209-241.

63. Winograd, T., & Flores F. (1986) *Understanding Computers and Cognition: A New Foundation for Design*. Addison-Wesley.

64. D'Andrade, R. (1981). The cultural part of cognition. *Cognitive Science*, 5, 179-195.

65. Cole, M. (2003). Culture and Cognitive Science. *Outlines. Critical Practice Studies*, 5(1), 3-15.

66. Bender, A., Hutchins, E., & Medin, D. L. (2010). Anthropology in cognitive science. *Topics in Cognitive Science*, *2*, 374–385.

67. Beller, S., Bender, A., & Medin, D. (2012). Should anthropology be part of cognitive science? *Topics in Cognitive Science*, *4*(3) 342-353.

68. Levinson, S. (2012). The original sin of Cognitive Science. *Topics in Cognitive Science 4*, 396–403.

69. Evans, N., & Levinson, S. (2009). The myth of language universals: Language diversity and its importance for cognitive science. *Behavioral and Brain Sciences*, *32*, 429-448.

70. Squire, L.R., Bloom, F.E., McConnell, S.K., Roberts, J.L., Spitzer, N.C. & Sigmond, M.J. (2003). *Fundamental Neuroscience* (2nd. Edition). Amsterdam: Academic Press.

71. Purves, D., Brannon, E., Cabeza, R., Huettel, S.A., LaBar, K.S., Platt, M., Woldorff, M.G., (2008). *Principles of Cognitive Neuroscience*. Sunderland MA: Sinauer.

72. Konopka, G. and Geschwind, D.H. (2010). Human Brain Evolution: Harnessing the Genomics (R)evolution to Link Genes, Cognition, and Behavior. *Neuron*, *68*, 231-244.

73. Richerson, P. J., Boyd, R., & Henrich, J. (2010). Gene-culture coevolution in the age of genomics. *Proceedings of the National Academy of Sciences*, 107(Suppl. 2), 8985–8992.
74. Dobzhansky, T. (1962). *Mankind Evolving: The Evolution of the Human Species*. Yale University Press.
75. Mayr, E. (2004). *What Makes Biology Unique? Considerations on the Autonomy as a Scientific Discipline*. Cambridge UK: University Press.
76. Neisser, U. (1967). *Cognitive Psychology*. Englewoods Cliffs NJ: Prentice-Hall.
77. Sanford, A.J. (1985). *Cognition & Cognitive Psychology*. New York: Basic Books.
78. Howard, D.V. (1983). *Cognitive Psychology: Memory, Language, and Thought*. New York: Macmillan.
79. Medin, D., Ross, B., & Markmann, A. (2005). *Cognitive Psychology* (4th Edition). New York: Wiley.
80. Piaget, J (1952). *The origins of intelligence in children*. New York: WW Norton & Co.
81. Piaget, J. (1977). *The development of thought: Equilibration of cognitive structures*. Oxford UK: Viking.
82. Piaget, J. (2005). *Language and Thought of the Child*. New York: Routledge.
83. Piaget, J., & Inhelder, B. (2015). *Memory and intelligence*. Psychology Press.
84. Vygotsky, L.S. (1962). *Thought and Language*. Cambridge MA: MIT Press.
85. Vygotski, L.S. (1978). *Mind in Society: The Development of Higher Psychological Processes*. Harvard University Press.
86. Fillmore, C. J. (1976). Frame semantics and the nature of language. *Annals of the New York Academy of Sciences*, 280(1), 20-32.
87. Lakoff, G. & Johnson, M.(1980). *Metaphors We Live By*. Chicago: Univ. of Chicago Press.
88. Langacker, R. (1986). An introduction to cognitive grammar. *Cognitive Science*, *10*, 1-40.
89. Langacker, R. (1991) *Concept, Image, and Symbol: The Cognitive Basis of Grammar*. Berlin: de Gruyter.

90. Fauconnier, G. (1994). *Mental spaces: Aspects of meaning construction in natural language*. Cambridge University Press.

91. Fauconnier, G., & Turner, M. (1998). Conceptual integration networks. *Cognitive Science*, *22*(2), 133-187.

92. Talmy, L. (2000). *Toward a Cognitive Semantics*. Cambridge MA: MIT press.

93. Chomsky, N. (1957). *Syntactic Structures*. The Hague: Mouton.

94. Chomsky, N. (1965). *Aspects of the Theory of Syntax*. Cambridge MA: MIT Press.

95. Chomsky, N. (1966). *Cartesian Linguistics*. New York: Harper & Row.

96. Chomsky, N. (1972). *Language and Mind*. New York: Harcourt Brace Jovanovich.

97. Chomsky, N. (1980). *Rules and Representations*. New York: Columbia Univ. Press.

98. Croft, W. & Cruse, D.A. (2004). *Cognitive Linguistics*. Cambridge UK: Cambridge Univ. Press.

99. Lee, D. (2001). *Cognitive Linguistics: An Introduction*. Oxford: Uxford Univ. Press.

100. Cognitive Science Society, "CogSci 2017: London" Annual Meeting (Retrieved August 15, 2018). http://www.cognitivesciencesociety.org/conference/cogsci2017/

101. Gao, R., Donoghue, T., & Voytek, B. (2017). Automated Generation of Cognitive Ontology via Web Text-Mining. *Proceedings of the 39th Annual Conference of the Cognitive Science Society* (pp. 2067-72). London, UK: Cognitive Science Society.

102. Hirst, W. (Ed.) (1988). *The Making of Cognitive Science: Essays in Honor of George A. Miller*. Cambridge: Cambridge University Press.

103. Wilson, R.A. and Keil F.C. (Eds.) (1999). *The MIT Encyclopedia of the Cognitive Sciences*. Cambridge MA: MIT Press.

104. Choi, B.C.K. & Pak, A.W.P (2006). Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. *Clinical and Investigative Medicine*, *29*, 351-364.

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Author contributions

R.N. conceived and designed the overall structure of the study, organized the intellectual content of the article, was involved with data analysis and data visualization design, and wrote most of the paper with systematic input from all co-authors. C.M.R. did the analysis of the faculty Ph.D. backgrounds, wrote the draft reporting on these data, and produced most of the figures following designs conceived by the entire team. J.R.D. and M.A. conducted the curriculum analysis. J.R.D. wrote the draft reporting on these data, and managed the work of a research assistant. M.A. wrote the supplementary information of this analysis. R.G. and A.S. conducted the authors' affiliation analysis, performed web-page scraping, and managed the computational work of two research assistants. R.G. wrote the draft reporting on these data and prepared the corresponding text for the supplementary information. R.G. performed the factor analysis and hierarchical clustering on the journal-journal citation data, produced the resulting dendrograms, and wrote the drafts of the results and supplementary information. A.S. provided input regarding scientometric methods. A.S. compiled all the supplementary information.

Competing Interests statement

The authors declare no competing interests.