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COMMENT

Topic: The State of Cognitive Science

Multidisciplinary Flux and Multiple Research Traditions within Cognitive Science

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Núñez et al. (2019) argue that cognitive science has failed either "to transition to a mature inter-disciplinary coherent field" (p. 782) or "to generate a successful [Lakatosian] research program" (p. 789). We argue that the former was never the intention of many early researchers within the field, while the latter is an inappropriate criterion by which to judge an entire discipline. However we concur with Núñez et al. (2019) that the individual disciplinary balance within cognitive science has changed over time. Of particular concern is the fact that the use of computational methods appears to be on the wane.

1 | INTRODUCTION

The outwards signs are that cognitive science is a mature discipline. The annual conference of the (US-based) Cognitive Science Society regularly has over 1000 attendees, while the Pacific-Asian International Conference on Cognitive Science is also thriving. Moreover, the Cognitive Science Society's first journal is now in its 43rd year, having just moved to twelve issues per year, and with the number of submission per year growing by about 75% over the last 10 years. And yet Núñez et al. (2019) argue on bibliometric and socio-institutional grounds that cognitive science is failing. Whether this is true depends on the goals of cognitive science. If its goal was simply to be a new science in its own right, then the analysis of Núñez et al. (2019) should carry significant weight. If its goal was instead to advance our understanding of mind, then different criteria for success are required. In this commentary we evaluate the interdisciplinary versus multidisciplinary nature of cognitive science and the relation between cognitive science and the Lakatosian concept of a research programme, before considering statistics from the journal *Cognitive Science* and what they imply for the health of the discipline. We conclude that some aspects of the Núñez et al. (2019) analysis are correct, and that some fields of cognitive science are less well-represented than one would perhaps like, but that this does not mean that cognitive science has failed.

2 | INTERDISCIPLINARITY VERSUS MULTIDISCIPLINARITY

The terms "multidisciplinary" and "interdisciplinary" are often used to characterise cognitive science, but the question of whether cognitive science is or should be one or the other is far from straightforward. A first issue concerns the definition of the terms. Núñez et al. (2019) adopt the definitions of van den Besselaar and Heimeriks (2001), who distinguish disciplinary from non-disciplinary research, with interdisciplinary and multidisciplinary being two distinct forms of non-disciplinary research. The difference between these two forms of non-disciplinary research is intuitively clear. The former refers to a coherent field with its own "theoretical, conceptual and methodological identity" (van den Besselaar and Heimeriks, 2001, p. 706), while the latter corresponds to a looser integration where multiple disciplines contribute to the subject under study, while retaining their individual disciplinary identities.

A critical claim of Núñez et al. (2019) is that cognitive science began with interdisciplinary aspirations, but that over the decades those aspirations have failed to materialise. One difficulty with this argument concerns the initial aspirations. While there were certainly some who argued for the interdisciplinary goal, this was not a universal position. As Núñez et al. (2019) notes, the first journal of the Cognitive Science Society was explicitly subtitled "A Multidisciplinary Journal". While Núñez and colleagues argue that this indicates "difficulties from the beginning" (p. 783), it perhaps reflects more the position of the journal's founders at the time — a position that aspired to multidisciplinarity rather than necessarily full interdisciplinarity. Indeed, the analysis of Schunn et al. (1998) of cross-disciplinary interactions within cognitive science is addressed to whether "the current state of cognitive science [in 1998] reflects the *multidisciplinary* ideals of its foundation" (p. 108; emphasis added). In a similar vein, von Eckardt (2001) endorses what she describes as a "holist" conception of multidisciplinarity, in which "multiple disciplines contribute to the execution of its research program" rather than a "localist" conception, in which "the individual research efforts of its scientists are, typically multidisciplinary" (p. 454). It seems that for many, multidisciplinarity rather than interdisciplinarity was the expectation.

The level of interdisciplinarity sought by Núñez et al. (2019) appears to involve equal representation within cognitive science of the six "founding" disciplines (anthropology, computer science, linguistics, neuroscience, philosophy and psychology). Beyond lamenting the dominance of (cognitive) psychology and the apparent marginalisation of anthropology, Núñez et al. (2019) do not offer any insight into why this level of interdisciplinarity has not materialised, whether it was in fact desirable or realistically achievable in the first place, or what its consequences might be.

Consider first whether any interdisciplinary endeavour involving six disciplines in equal parts is realistic. If one is to judge success by a uniform undergraduate syllabus, then that syllabus would need to include significant training in six disciplines within a single degree. This is unrealistic — graduates would be unlikely to develop the kind of in-depth knowledge of any of the disciplines obtained by their single-discipline peers. They would be Jacks/Jills of all trades, but masters of none.

Where true interdisciplinarity has been successfully achieved, it seems that many fewer disciplines are involved. The only successful case of interdisciplinarity cited by Núñez and colleagues is biochemistry — an interdisciplinary mix of just two disciplines. There are presumably other successful cases. Two that would seem of special relevance to the current argument are psycholinguistics and cognitive neuroscience. While it is unclear whether Núñez and colleagues would consider these successful cases of interdisciplinarity, it is noteworthy that each of these again involves just two traditional disciplines. The level of interdisciplinarity sought by Núñez et al. would seem, at least at the undergraduate level, to be idealistic rather than realistic.

The arguments of Núñez et al. (2019) also assume that the founding disciplines a) have equal potential contributions, and b) have themselves been static over the years. The former is far from clear. Gardner (1985), the primary source of the characterisation of cognitive science by Núñez et al. (2019), cites five features that are shared by most

(but not all, as Gardner explicitly states) involved in cognitive science. The first of these, as quoted by Núñez et al. (2019), is "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" (Gardner, 1985, p. 6). This would seem to immediately place (cognitive) psychology (itself in its infancy at the time) in centre stage, while de-emphasising neuroscience and anthropology. The second feature, "that central to any understanding of the human mind is the electronic computer" (Gardner, 1985, p. 6), similarly prioritises the emerging discipline of computer science. Thus, while all six founding disciplines clearly have roles to play within cognitive science, there is good reason why some disciplines (notably psychology and computer science) might be more central than others. This is not to say that cognitive science has nothing to learn from anthropology or philosophy, or that tight integration with cognitive neuroscience would be undesirable.

Disciplines change over time, as methods develop and as the scientific focus shifts amongst problems. Psychology and computer science are no different. One of the most profound effects of the cognitive revolution was the emergence of a new type of psychology — cognitive psychology. It should neither be forgotten that this discipline did not exist when cognitive science was first emerging, nor surprising that this discipline shares a great deal with cognitive science. The continuing close relationship between cognitive psychology and cognitive science reflects their shared assumptions concerning the cognitive level of analysis. Yet both fields continue to evolve. While Núñez et al. (2019) implies that cognitive science is being consumed by cognitive psychology, an alternative view is that cognitive psychology is morphing into cognitive science.

But why should cognitive psychology and cognitive science be merging, rather than, for example, neuroscience and cognitive science, or anthropology and cognitive science? There are many factors that are plausibly at play. One is arguably that psychology (both as a discipline, and in terms of psychology departments) is particularly accepting of methodological diversity, given its breadth (including social psychology, developmental psychology, educational psychology, "abnormal" psychology, etc.). A second is that the cognitive perspective is more central to cognitive psychology than it is to, say, anthropology, where a cognitive approach is just one of several (such as sociocultural or archaeological; see Bender, 2019) that might be adopted. Other arguments relate more specifically to the individual founding fields. Neuroscience, for example, has adopted the cognitive perspective in the interdisciplinary field of cognitive neuroscience, and computer science (or at least that part of computer science that relates most closely to cognitive science) is currently driven by issues in machine learning, technological problems needing engineering solutions, and the allure of big budgets in the tech. industries, leading to a sharper schism between artificial intelligence and natural intelligence than was perhaps originally conceived (even though many of the successes of current AI technology have their foundations in cognitive science).

Within this context, the emergence of cognitive neuroscience, computational neuroscience and psycholinguistics deserve special comment. The success of these pairwise enterprises demonstrate that there are important gains to be had from working across the founding disciplines of cognitive science, but their success equally supports the hypothesis that the interdisciplinary mix of six disciplines is simply too great a leap, and that for such grand endeavours, a more realistic approach is the multidisciplinary one, in which expertise and insight is shared across multidisciplinary collaborations.

3 | WHOLE DISCIPLINES ARE NOT LAKATOSIAN RESEARCH PROGRAMMES

A second sense in which cognitive science has failed, according to Núñez et al. (2019), is in the generation of a progressive Lakatosian research programme. Some context is required to evaluate this assertion. Lakatos (1970) was

concerned that the view of science developed by Popper (1934/2005, 1963/2014), with its emphasis on falsification and bold conjectures, was idealistic and prescriptive, and did not reflect the actual methods of practicing scientists. He adopted an historicist approach to the philosophy of science, studying the notebooks of key scientists (Newton, Copernicus, Lorentz, Einstein, etc.), in developing his concept of a "research programme". Lakatos argued that in practice scientists did not react to failed predictions by rejecting their theories (as a direct reading of Popper might suggest). Rather, in practice scientists tended to modify their theories, but in a way that retained a hard core of assumptions. Experiments were directed at peripheral hypotheses, and only once such hypotheses were sufficiently corroborated were they migrated or accepted into the theory's hard core. Critically for the current discussion, Lakatos was concerned with the practice of individual scientists, not of disciplines as a whole. To argue that cognitive science is a failed Lakatosian research programme is a category error.

The primary argument that Núñez et al. (2019) cites in support of their claim that cognitive science is a degenerative (and consequently failed) research programme is that it "has seen its hard core progressively challenged and to some extent refuted from within by various schools and approaches" (p. 789). But as argued above, Lakatosian research programmes are more fine grained than scientific disciplines. When considered in the light of the research programmes of individual scientists, even the "various schools and approaches" — symbol systems, parallel distributed processing, Bayesian cognitive science and non-representational approaches — are more course-grained than true Lakatosian research programmes. A more accurate rendition of the concept within cognitive science would seem to relate to the research programmes of, for example, Newell in the development of Soar (see in particular Newell, 1990, for an explicit appeal to Lakatos) or Anderson in the development of the ACT-R cognitive architecture (see Cooper, 2006, for a Lakatosian analysis of each of these research programmes), but the concept might be equally well applied to the research programmes of Hinton with respect to learning within neural networks, or Busemeyer with respect to quantum probability theory and decision making, or Dayan with respect to theoretical neuroscience and reinforcement learning, and so on.

The fact that there is disagreement between theorists with respect to representational issues does not indicate a failure to establish a putative hard core of cognitive science or a failure of the discipline. While there are indeed clearly distinct approaches within cognitive science, with clearly distinct commitments, these different approaches are perhaps more accurately characterised not as Lakatosian research programmes but as "research traditions", in the sense of Laudan (1978). From this perspective, the utility of the different approaches should be judged in terms of the rate at which problems are being solved within each research tradition. It is also noteworthy that Laudan (1978) suggests that individual scientists might accept one tradition while pursuing another. Multiple research traditions within a discipline are therefore not problematic. In fact, Laudan (1978) considers them to be a positive sign of a field's vigour.

4 | SUBMISSION TRENDS IN COGNITIVE SCIENCE AND THEIR IMPLICATIONS

One key analysis of Núñez et al. (2019) concerns the departmental affiliations of authors who have published in *Cognitive Science* since the year 2000. The implicit assumption is that if cognitive science is a well-rounded field then all contributing disciplines should be represented approximately equally. Given the characterisations of cognitive science cited by Núñez et al. (2019) and quoted above, this does not seem to be justified. If cognitive science was "[m]otivated by the shared urge to overcome the limitations of behaviourism that rules mid-twentieth-century psychology and fuelled by the emergence of the computer technology of the 1940s and 1950s" (Núñez et al., 2019, p. 782) — a

characterisation that we accept — then it seems reasonable that two of the contributing disciplines — psychology and computer science — should be more central. Again, this is not to deny that anthropology, linguistics, neuroscience, philosophy, and potentially other disciplines (such as education) have much to offer cognitive science.

A second concern with the analysis of departmental affiliation is that it assumes that departments themselves are oriented to a single discipline. Given that cognitive science departments are rare, department affiliation might seem a good proxy for disciplinary orientation, but anecdotally this assumption seems unfounded. My own department, explicitly named "Psychological Sciences" in the plural, includes academic staff with undergraduate degrees in physics, mathematics/computer science, law and English, as well as of course in psychology.

Arguably a more accurate way of assessing the disciplinary make-up of cognitive science is through an analyses of the classification information for manuscripts submitted and/or accepted for publication by *Cognitive Science* (see also Goldstone and Leydesdorff, 2006). On submission, authors select one or more *fields* (e.g., psychology, computer science, …), one or more *topics* (e.g., analogy, concepts, problem solving, …) and one or more *methods* (e.g., developmental experimentation, mathematical modelling, philosophical analysis, …). This classification data, which has been captured in this way by the submission software since August 2002, is primarily used to aid in the selection of reviewers, but it provides a more accurate characterisation of manuscript content and orientation than departmental affiliation.

Figure 1 shows the percentage of submissions nominating each contributing discipline in the periods 2002 – 2006 and 2015 – 2019.[1] Manuscripts may nominate multiple fields, and for each pair of disciplines, the thickness of the corresponding line in Figure 1 indexes the proportion of manuscripts nominating both fields from the pair. Consistent with the analysis of Núñez et al. (2019), psychology dominates and anthropology contributes least, but the contribution from philosophy is more substantial than suggested by the affiliation analysis presented by Núñez et al. (2019).

There are at least two additional striking features of Figure 1. Firstly, while psychology dominates, it does so in collaboration with other disciplines. In both periods, a substantial proportion of manuscripts that cite psychology also cite a second discipline. Perhaps of some concern is the fact that in the earlier period these pairwise relations are stronger than the later period, with all pairs apart from psychology/linguistics seeing a decline over time. Nevertheless, all pairwise disciplinary conjunctions are represented in both periods. This in itself indicates a remarkable degree of multidisciplinarity.

Secondly, there is some variation in the balance of the contributing disciplines across time, with a slight decline in the proportion of manuscripts citing psychology, philosophy, AI/CS and biology/neuroscience, and an increase in the proportion citing linguistics. Do these changes represent noise or do they reflect something more substantive? Table 1 shows the results of chi-squared analyses on the number of submissions associated/not associated with each field as a function of the period of submission. The analyses show that many of the changes are indeed statistically significant. Contrary to the analyses of Núñez et al. (2019), the dominance of psychology appears to be on the decline, while linguistics has increased in its contribution over the period. Yet Núñez et al. (2019) is correct to suggest an increasing disciplinary imbalance, with recent years seeing a significantly smaller proportion of manuscripts citing AI/CS and biology/neuroscience, but also of psychology. These figures do question the multidisciplinary health of cognitive science, particularly when coupled with the decrease over time in the proportion of manuscripts citing conjunctions of fields indicated by Figure 1.

[1] The submission system includes nine fields, which broadly correspond to the contributing disciplines. The fields are shown individually in Table 1, but Figure 1 combines data from biology and neuroscience and from artificial intelligence and computer science. The proportion of submissions for the ninth field, education, are not shown in the figure so as to allow direct comparison with the disciplines considered by Núñez et al. (2019). All submissions between August 1st, 2002 and August 31st, 2019 are included in the figures.

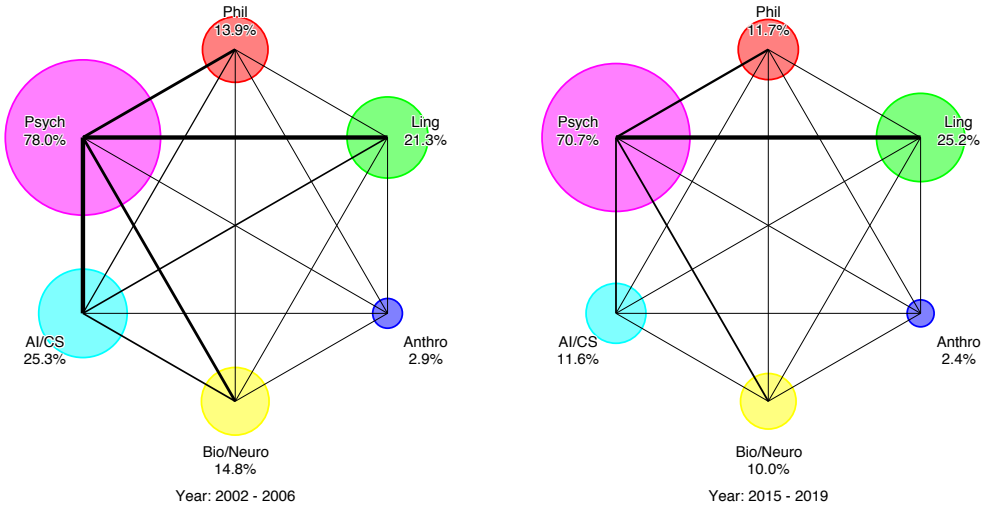

FIGURE 1 The percentage of submissions by field to *Cognitive Science* in the periods 2002–2006 and 2015–2019. For each field, the area of the corresponding circle is proportional to the percentage of submissions that indicated that field. The thickness of lines between fields represents the proportion of submissions indicating both fields.

A more fine-grained analysis of the changing contributions of different fields can be obtained from the "methods" classification data. Table 2 shows the analyses of this data, paralleling Table 1. Several methods which featured little or not at all in early submissions are now present at modest levels (philosophical analysis, neuropsychology and eye tracking), with the largest increase being in the use of philosophical analysis. In contrast, the use of experimental, computational and mathematical methods have all decreased, as have methods relating to knowledge representation and logic. Whether such changes indicate increasing or decreasing integration within the field of cognitive science depends of course on the baseline level. The decrease in experimental methods is arguably not of great concern given that high level of such methods in 2002-2006, and given that they continue to dominate (being selected for over 30% of submissions). Moreover this decrease is possibly reflective of the small decline in the contribution from psychology. However, the drop in computational and mathematical methods (and associated drops in knowledge representation and logic) is more concerning. Computer simulation, in particular, has dropped from over 20% in 2002–2006 to under 10% in recent years.

5 | CONCLUSION

While it is far from clear whether cognitive science could ever achieve the level of interdisciplinarity sought by Núñez et al. (2019), or whether such a level of interdisciplinarity would be desirable, it is clear that the multidisciplinary character of cognitive science has shifted over time. Such shifts are inevitable given that science is not (and surely should not be) regulated in a top-down fashion, and so they are not necessarily a cause for concern. Moreover one cannot lay down in advance laws of how a discipline should evolve, as science is an organic process that thrives on

TABLE 1 The percentage of articles submitted to *Cognitive Science* in each field during the periods 2002–2006 and 2015–2019, together with statistical tests of the difference. The fields are the nine available to authors when they submit their manuscripts. For each field, the probability of change was assessed with a χ^2 test of association performed on the 2×2 contingency matrix of counts of submission indicating the field versus submissions not indicating the field in each period.

Field	2002–2006	2015–2019	Direction	$\chi^2(1)$	p
Anthropology	2.85%	2.35%	—	0.533	0.465
Artificial Intelligence	18.68%	8.05%	↓	57.985	< 0.001
Biology	4.02%	1.42%	↓	15.907	< 0.001
Computer Science	13.10%	6.38%	↓	30.160	< 0.001
Education	7.78%	6.25%	—	1.937	0.164
Linguistics	21.27%	25.20%	↑	4.428	0.035
Neuroscience	12.71%	9.10%	↓	7.376	0.007
Philosophy	13.88%	11.70%	—	2.272	0.132
Psychology	77.95%	70.71%	↓	13.890	< 0.001

methodological plurality and individual creativity (Feyerabend 1975; see also Gentner 2019).[2] However, with respect to cognitive science and given the central role of computation in the discipline as originally conceived, the decline in work involving mathematical and computational methods must be of concern. Without the perspective of such methods, the potential of cognitive science will be limited.

While their tone is pessimistic, the conclusion one should draw from the analysis of Núñez et al. (2019) is unclear. In our view, the conclusion that should be drawn is that cognitive science has not failed. Without it we would not have automatic translation, or self-driving vehicles, among other artefacts. However, more needs to be done to reintegrate core computational and formal methods into the discipline, while also not neglecting the essential contributions from anthropology, philosophy and neuroscience, if its potential is to be fully realised. Our view is not, though, that cognitive psychology is taking control of the discipline by stealth, but that computation is relinquishing ground, as those trained in computation are drawn in other directions.

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[2] Arguably the current movement towards pre-registration, when taken to its extreme, is a similar constraint on methodological plurality.

TABLE 2 The percentage of articles submitted to *Cognitive Science* using each of the 23 methods available with the journal's submission classifications, during the periods 2002–2006 and 2015–2019, together with statistical tests of the difference. For each method, the significance of change was assessed with a χ^2 test of association performed on the 2×2 contingency matrix of counts of submission indicating the method versus submissions not indicating the method, in each period.

Method	2002–2006	2015–2019	Direction	$\chi^2(1)$	p
Increasing:					
Cross-cultural Analysis	1.69%	3.22%	↑	4.632	0.031
Eye Tracking	1.17%	4.95%	↑	20.834	< 0.001
fMRI	0.00%	0.62%	↑	4.794	0.029
Neuropsychology	0.00%	2.35%	↑	18.435	< 0.001
Philosophical Analysis	0.00%	5.57%	↑	44.650	< 0.001
Statistics	5.71%	8.73%	↑	6.671	0.010
Stable:					
Cross-linguistic Analysis	2.59%	3.03%	—	0.360	0.549
Electroencephalography (EEG)	1.95%	2.29%	—	0.292	0.589
Animal Experimentation	1.30%	0.74%	—	1.753	0.185
Clinical Methods	0.65%	0.56%	—	0.074	0.785
Developmental Experimentation	5.84%	4.33%	—	2.567	0.109
Ethnography	1.04%	0.68%	—	0.840	0.360
Mathematical Modeling	12.45%	9.91%	—	3.527	0.060
Neuro-imaging	1.43%	0.99%	—	0.887	0.346
Robotics	1.69%	1.11%	—	1.329	0.249
Single-cell Recording	0.26%	0.06%	—	1.621	0.203
Decreasing:					
Computational Neuroscience	4.67%	1.98%	↓	13.617	< 0.001
Computer Simulation	20.10%	9.60%	↓	50.957	< 0.001
Human Experimentation	37.48%	32.94%	↓	4.771	0.029
Knowledge Representation	15.56%	5.82%	↓	60.684	< 0.001
Logic	5.19%	2.48%	↓	11.839	0.001
Neural Networks	14.14%	4.02%	↓	78.940	< 0.001
Symbolic Computational Modeling	7.78%	3.16%	↓	25.157	< 0.001

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