International Advance Journal of Engineering, Science and Management (IAJESM)
ISSN -2393-8048, July-December 2022, Submitted in December 2022, iajesm2014@gmail.com

A review of Web of Science data spanning more than a century suggests that physics is expanding quickly and becoming more interdisciplinary.

Malti*, Deapartment of Physics, H.No. 532, Housing Board Colony, Jind, Haryana (India)
Email id- mudgilmalti@gmail.com

Abstract

Over the past forty years, core physics has become less exclusive and more open to the vast amount of non-physics literature. In contrast, interdisciplinary physics started to function as a separate discipline that was still closely tied to physics but had a more tribal feel to it. The underlying structure of physics Instead of being a single field, physics is separated into a number of subfields, each of which has its own set of intellectual challenges, organisational structures, and cultural norms. With a fourfold rise in citations to physics papers, interdisciplinary physics was far less self-referential and closely tied to core physics. In 2000, however, when both core and interdisciplinary physics suffered a sharp fall, the self-referential aspect of interdisciplinary physics was only slightly more pronounced. In other words, core physics has evolved over the past forty years to become less exclusive and more open to the vast amount of non-physics literature.

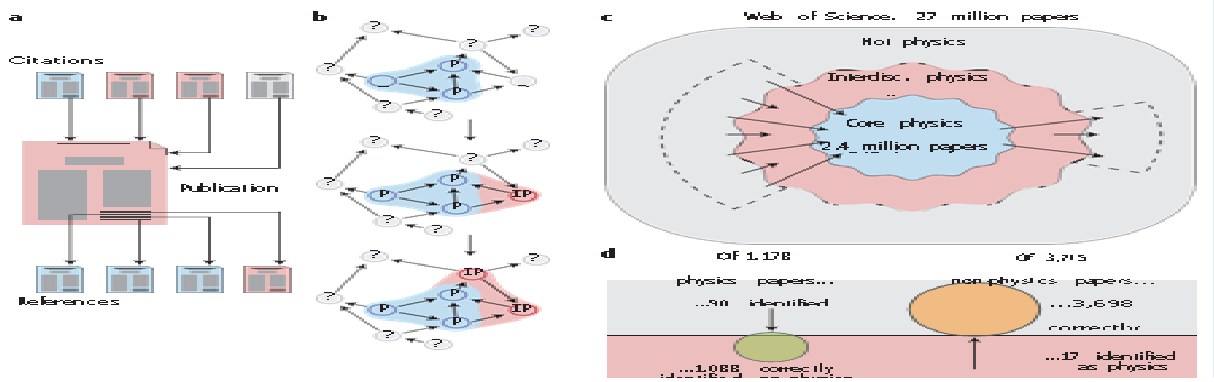
Keyword: core physics, DNA, ratio of the curves, electromagnetic, atomic, and plasma physics

Introduction

The typical story of physics is one of paradigm shifts, starting with the Copernican Revolution and ending with Einstein's annus mirabilis. The stories also provide the impression that genius exists in isolation; the lone physicist is isolated from other fields and is unaffected by society norms.The truth, however, is rather different: physics has always been in conversation with other fields, whether it is theology, chemistry, or mathematics. The idea that complex events can be understood in terms of a limited set of universal laws is what cuts across disciplinary boundaries and is the main methodology driving this discussion. It is becoming more and more out of date and incorrect to define physics as the study of the qualities of matter and energy in this era of multidisciplinary science, biological physics, network science, and econophysics. Thus, we are driven to reexamine the question, "What is physics?" Is it engineering or physics when two engineers unintentionally discover cosmic microwave background radiation? Is it biology or physics when a physicist discovers the structure of DNA? Is physics' multidisciplinary role something that has just recently emerged or is it a long-standing aspect of the subject? Is physics surviving or prospering, becoming more multidisciplinary or more secluded? We shall rely on the methodology that physics invented to respond to these inquiries: gathering evidence from which to make conclusions.

Perspective

A research publication is the primary form of communication in science, and its references and citations provide extensive contextual information about the paper's subject and field (panel a). We analysed this data to comprehend the origins and development of physics.We used 2.4 million publications from 242 physics journals included in Web of Science (WoS), a list created by merging data from Wikipedia, Scopus, and Scimago, to identify the whole corpus of core physics papers (www.scimagojr.com). In panel b, these core physics papers are displayed as blue nodes and denoted with the letter P.



From about 4% of the scientific literature in 1945 to about 10% in 1980, the literature produced in physics journals has remained roughly constant (Fig. 1b). Similar trends have been observed in interdisciplinary physics, which increased from 6% in 1945 to a maximum of 18% in 1964 before settling at 12% after 1980. Since the 1980s, the greater physics literature has made up about 22% of all scientific publications; this astounding percentage demonstrates how deeply physics is ingrained in the larger scientific effort. Does the exponential expansion in the number of physicists or their productivity over time account for the exponential growth of the physics literature? The disambiguated authorships of papers published by the American Physical Society were utilised to help us answer this question (ref. 13 and Sinatra et al., manuscript in preparation). We discovered that the number of authors has grown at the same rate as the number of papers (Fig. 1c). This leads us to the conclusion that the expansion of physics literature is primarily fueled by the rise in authorship. However, we do notice non-trivial changes in productivity. In fact, during the past 15 years, the average number of articles each physicist has co-authored has increased from less than one before the year 2000 to over one now. For the first time in the previous 15 years, each physicist co-authored more than one paper (Fig. 1d, black curve). The impact and its nuances Does influence expand steadily along with physics as it advances? We utilised the average number of citations each manuscript receives within 10 years of publication, or c10 (Fig. 2a), as a proxy for impact16,17 in order to answer this question. We discover an intriguing surge in influence for works published between 1955 and 1965, suggesting that physics experienced a "golden age" about 1960.

A continuous increase in both the number of papers and the number of references per paper often drives a steady increase in citations. None of these curves exhibits discontinuities in the 1960s, but the literature's exponential expansion continued over this time (Fig. 1a), and the average number of citations per paper increased steadily from two in 1900 to almost 15 in 2000. (Fig. 2b). However, there was a definite break in the way we cited sources in the 1960s. In fact, physics was at its most narrow in the late 1930s, with the majority of papers published in the previous four years receiving citations (Fig. 2c,d). Because there were insufficient publications published during the war, the average age of references rapidly increased after World War II18,19. Citing pre-war studies, the scientific community simply carried on where it had left off before the war. The myopic citation style returned when the literature recovered, with the age of references hitting a new low in 1960. However, this was followed by a slow but persistent shift in citation practises that is still present today: physicists are consistently reading farther back in the canon and referencing older and older publications (Fig. 2c,d). We believe that peer review is what caused this significant change. In fact, papers were only accepted on an editorial discretion basis prior to the 1960s20. The demand for expert opinion has arisen as a result of the specialisation of science, but it was challenging to accomplish until the advent of photocopying in 1959. (ref. 21)

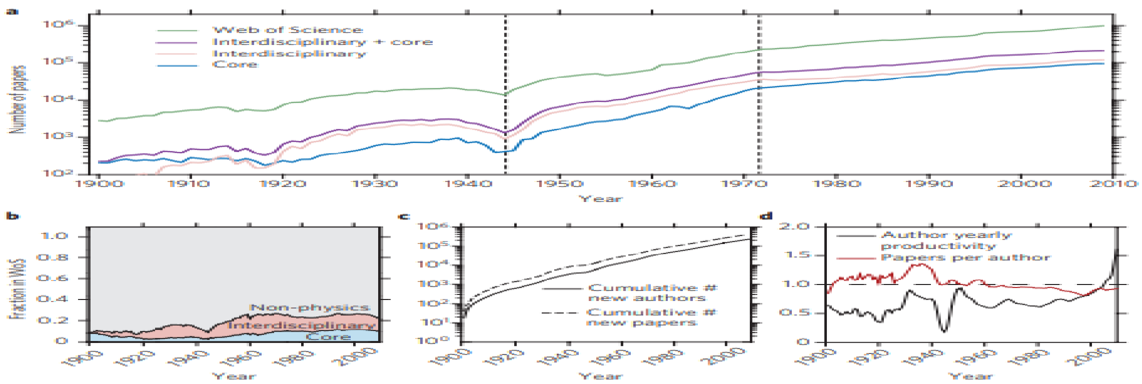


Figure 1 The evolution of physics. **a**, Changes in the number of papers in physics and the Web of Science (WoS) data over the past century. The plot shows that the literature has been growing exponentiallyover time. The growth was steepest between 1950 and 1970, doubling every 6.5 years. After 1970, the doubling time increased to 18.7 years. Growth was only disrupted around 1915 and 1945 due to the WorldWars. **b**, The fraction of physics core papers grew slowly over time, from 4%

in 1920 to about 10% in 2000 (blue). The fraction of interdisciplinary physics papers (red) showed a dip during World War II, but recovered to a stable fraction of about 12% of the whole scientific literature. **c**, During the past century the number of authors increased at the same rate as the number of papers. **d**, Overall productivity, representing the number of papers per author, the ratio of the curves shown in panel **c**, has been fluctuating between 1900 and 1950 in the vicinity of one. In contrast, the number of papers co-authored by each physicist has been less than one during the past 100 years, but increased sharply in the past 15 years. This growth is a direct consequence of collaborative effects: individual productivity is boosted because physicists end up on many more papers as co-authors.

Peer review gained popularity in the 1960s; Nature made it official in 1967. In addition to increasing references to earlier material, the reviewer's capacity to identify pertinent work also caused a behavioural shift in the authors, urging them to give earlier work more attentive credit. The impact peak of the 1960s can be explained by this shift in referencing practises. Indeed, while late 1950s articles were still heavily cited by papers that came out just after them, they also received extra support from subsequent papers. However, as a result of having to compete for citations with much older works, publications from the late 1960s started to lose citations. In fact, a null model shows that a shift in the referencing practises seen in Fig. 2d does cause a surge in the number of citations for articles written in the 1960s (Fig. 2a). As a result, the 1960s impact peak may not necessarily be indicative of a golden age of physics; rather, it was probably an unintentional result of the increasing adoption of peer review, which caused deeper reference to arise. A systematic difference in impact between core and interdisciplinary studies is also shown in Figure 2a. We investigated the citation patterns of core and multidisciplinary physics in 1960, when the impact gap was at its widest, and in 2000, when it had nearly vanished as a result of the constant increase in the effect of interdisciplinary physics publications, in order to comprehend its origin. As seen in Fig. 2e, core physics was extraordinarily self-referential in the 1950s–1960s, sending 11.1 times more citations to works in physics journals than one would predict by chance.

Interdisciplinary physics was substantially less self-referential and tightly related to core physics, with a fourfold increase in referrals to physics publications. However, interdisciplinary physics' self-referential nature somewhat outpaced core physics' in 2000, which saw a major decline in both. In other words, core physics has become less tribal during the past forty years and more receptive to the large body of non-physics literature. Interdisciplinary physics, in contrast, began to function as a distinct science that was closely related to physics but also became more tribal. The fundamental design of physics Physics is not a single field; rather, it is divided into several subfields, each of which has its own intellectual problems, working methods, and culture. We divided all of the physics literature (core and interdisciplinary) into 10 main subfields using the Physics and Astronomy Classification Scheme (PACS) of the American Physical Society.

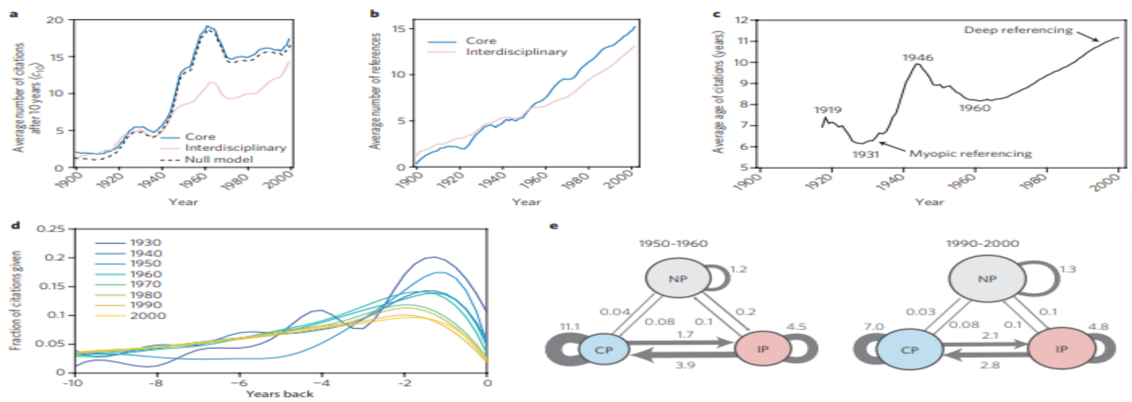


Figure 2 | The evolution of impact. **a**, We used the number of citations collected over 10 years, $\langle c_{10} \rangle$, as a proxy of a publication's long-term impact. The average impact of physics papers has grown from 1900 to 1950, and papers published between 1950 and 1960 received the most citations. The dotted line corresponds to a random null model, obtained by using the growth in number of papers (Fig. 1a), the increasing number of references (panel **b**) and different citation age distribution (panel **d**). These three time-dependent factors together can reproduce the observed impact peak in the 1960s. **b**, The average number of references per paper has been increasing steadily over time. **c**, The average

age of the references of papers published in American Physical Society journals, documenting large variations in the depth of referencing over the past century. **d**, The probability of citing past papers for different years shows again remarkable shifts incitation patterns from myopic referencing in the 1930s–1950s to the current, increasingly deep referencing. **e**, The flow of citations between the core physics(CP), interdisciplinary physics (IP) and the non-physics (NP) literature in the decade before 1960 and before 2000. Node sizes are proportional to the logarithm of the number of papers published in each area. The weight of each link corresponds to the number of citations divided by expected citations, for instance, a weight 2 indicates that citations are twice the number of expected citations in a null model, where citations are randomly redistributed between areas.

These subfields naturally group into three domains, as shown in Figure 3a22. Condensed matter and interdisciplinary physics and associated fields (IPR), which differ from the interdisciplinary physics corpus specified in Box 1, make up the first and largest domain. IPR is the subset of publications belonging to PACS code 80. The third area includes publications on particle, nuclear, and astrophysics, while the second domain covers topics including electromagnetic, atomic, and plasma physics. Statistics show that each domain's subfields consistently cite one another while rarely doing so with subfields from other domains. General physics, which is significantly co-cited by numerous subfields from each area, connects these three realms. The loops in Fig. 3a show how frequently each subfield cites other publications in that subfield, revealing an astonishing trend: the smaller a subfield, the more self-referential it is. In fact, we discover that the amount of self-referencing inside a subfield declines as N-1 with N papers (Fig. 3b). For instance, articles in the smallest subfields of plasma, nuclear, and astrophysics cite themselves 23 times more frequently than would be predicted by chance. When compared, The four main subfields, condensed matter, IPR, and general physics, only cite themselves roughly four times more than would be predicted by chance. Some subfields experience systematic citation obstacles as a result of this self-referential character (Fig. 3c). The most affected discipline is nuclear physics, which exhibits a 23-fold self-referencing and up to seven times less citations than would be expected by chance from the four major subfields. Because it is not undercited by any other area, general physics is not included in Fig. 3c, reinforcing the importance of this subfield in Fig. 3a.

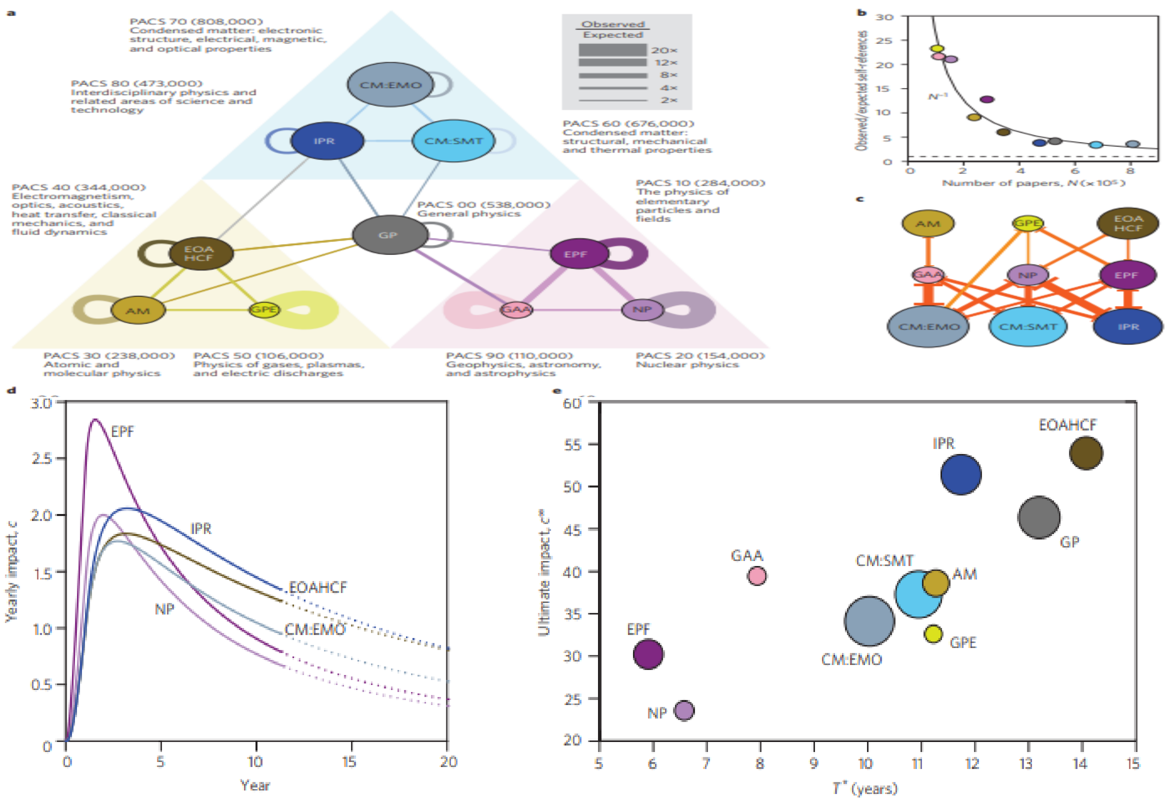


Figure 3 | The anatomy of physics. We classified each physics paper from the core and interdisciplinary literature into one of the ten major Physics and Astronomy Classification Scheme (PACS)-based subfields of physics, available after 1975. Since only 5% of these papers have PACS numbers, 3.7 million of them do not show subfield-specific citation bias, hence could not be assigned a subfield by our algorithm. The remaining 1.9 million papers were successfully assigned a subfield, allowing us to explore the inner structure of the physics literature. Note that 1.1 million papers have multiple PACS numbers, hence they may belongto multiple subfields. **a**, The co-citation patterns between the different physics subfields. Node sizes are proportional to the number of papers published in each subfield. Two subfields are connected if the number of citations between them significantly exceeds the expected citations, the line widths for all links, shown in the key, correspond to how many times the observed reference exceeds the random expectation. We find that core physics naturally clusters into three domains, as indicated by the colours of the clusters. General physics plays a central role, linking the three domains together. The loops on each node show the degree of self-referencing of the corresponding field. **b**, The smaller a subfield, the more its reference list is biased towards papers in the same subfield. **c**, A link between two subfields is evidence of citation barriers, where two areas have a significantly smaller number of citations than expected by chance. The highest citation barriers, up to nine times fewer citations than expected by chance, are between GAA and CM:EMO, and between NP and IPR. **d**, The yearly citations, *c*, of papers published in 2000 in selected subfields. Dotted curves indicate predictions. **e**, The ultimate impact, c^{∞}, representing the total number of citations a typical paper receives (that is, the area under the curves shown in panel **d**), versus impact time, *T**, for papers published in 2000 in each subfield, representing the typical time over which a paper collects its citations. The symbol size is proportional to the number of papers published in each subfield.

We chose all papers published in 2000 within each PACS code and fitted a citation model17 to their citation trajectories to forecast their average amount of citations over the following 20 years. This allowed us to understand the long-term influence of articles in each area (Fig. 3d). These fits offer two crucial parameters: ultimate impact (c), which represents the total number of citations a typical manuscript will accrue over the course of its lifetime, and impact time (T*), which indicates the normal duration of a work's citations. The biggest overall influence is seen in the fields of electromagnetism and transdisciplinary physics, as shown in Fig. 3e, where a typical work will receive more than 50 citations in its lifespan. Additionally, their impact times are substantially longer than those of other subfields (T* = 11.74 and 14 years, respectively), demonstrating that high-impact articles take a very long time to gain citations. when they are alive. The insular nature of these subfields, which are nearly seven times undercited by the greatest domain of physics (Fig. 3c) and exhibit the highest level of self-referencing, helps to explain in part why they have such a low influence. When taken as a whole, Fig. 3 illustrates how varied physics is, with distinct subfields having quite different effects, histories, cultures, and capacities for interacting with other areas of physics.

What should be done next?

Many of us who are involved in physics hiring committees or thesis defences have faced the dilemma of determining whether a certain body of work or scientist qualifies as a physicist. The examination of the physics literature explains why the discussion is often pointless: there is no single accepted definition of what physics is. On one extreme, there is the significant body of work that has been published in physics journals and, as a result of the publication venue, tends to be accepted by the majority of physicists. However, as we have demonstrated, there is a considerably bigger body of physics literature that, despite being published outside of physics journals, is identical to the core physics literature in terms of subject matter and citation style. Without many of the publications in it, physics as we know it would not be possible. The examination of this extensive corpus provides a wealth of quantitative data that reveals the structure of the field. It reveals the tribal nature of the various physics subdisciplines, showing, for instance, that our ability to describe a field like physics using sets of journals is long gone. The smaller the specialty, the more self-referential it becomes. In this context, nuclear and particle physics stand out since they are not only the most self-referential subfields of physics but also significantly distanced from most other subfields in terms of citations.

Papers in those fields burn out quickly and have a substantially lower overall impact than those of their peers in other subdisciplines as a result of this isolation, which has a huge negative impact. These patterns conceal critical weaknesses since, according to study in ecology and the adoption of new technologies, such monocultures are frequently destined for extinction. Our knowledge of how physics interacts with other academic fields is still developing. Obstacles include the scarcity of instruments capable of mining the text of research papers and the lack of precise records for each scientist's publications. But because these technologies are being created so quickly, we are moving closer to a day when it will be possible to evaluate every detail of a hypothesis regarding the origins and development of a field or discovery. These developments provide us a chance to think more deeply about how physics develops and how a particular discovery affects later work in and outside of physics, moving beyond broad generalisations like the idea of paradigms. . Such quantitative insight could assist us in identifying as yet untapped study areas because the most beneficial discoveries emerge from the cross-pollination of many fields — recombining previously isolated ideas and resources24. In order to unlock scientists' creative potential and increase their long-term influence, we may need to modify the way we fund institutions. This will require a deeper knowledge of the best paths for innovation.

Acknowledgements

The AFOSR award FA9550-15-1-0077 supports R.S., M.S., and A.L.B. P.D. is funded by the Communaute Francaise de Belgique's Research Department and the National Foundation for Scientific Research (FNRS) (Large Graph Concerted Research Action). The AFOSR is funding D.W. through grant FA9550-15-1-0162. Additionally, the James S. McDonnell Foundation provides funding for R.S. The Future and Emerging Technologies Project 317 532 "Multiplex," funded by the European Commission, also provides assistance to A.L.B. We appreciate I. Georgescu's many insightful comments and suggestions during the course of this project, as well as J. De Nicolo's assistance with managing the WoS data.

References:

1. Kuhn, T. The Structure of Scientific Revolutions (Univ. Chicago Press, 1996).
2. Barabasi, A-L. Nature Phys. 8, 14–16 (2011).
3. Main, P. & Tracy, C. Phys. World 26 (4), 17–18 (2013).
4. Donald, A. Phys. Biol. 11, 053008 (2014).
5. Lorenz, E. N. J. Atmos. Sci. 20, 130–141 (1963).
6. Fortunato, S. Phys. Rep. 486, 75–174 (2010).
7. Zhu, X. Semi-Supervised Learning Literature Survey Tech. Rep. 1530 (Univ. Wisconsin-Madison, 2005).
8. Shen, H-W. & Barabasi, A-L. Proc. Natl Acad. Sci. USA 111, 12325–12330 (2014).
9. Hubbard, J. Proc. R. Soc. Lond. A 276, 238–257 (1963).
10. Hopfield, J. J. Proc. Natl Acad. Sci. USA 79, 2554–2558 (1982).
11. Mehra, J. The Golden Age of Theoretical Physics (World Scientific, 2001).
12. Bornmann, L. & Mutz, R. J. Assoc. Inf. Sci. Technol. (2015).
13. Deville, P. et al. Sci. Rep. 4, 4770 (2014).
14. Wuchty, S., Jones, B. & Uzzi, B. Science 316, 1036–1039 (2007).
15. Pavlidis, I., Petersen, A. M. & Semendeferi, I. Nature Phys. 10, 700–702 (2014).
16. Radicchi, F. & Castellano, C. Phys. Rev. E 83, 046116 (2011).
17. Wang, D., Song, C. & Barabási, A-L. Science 342, 127–132 (2013).
18. Redner, S. Phys. Today 58 (6), 49–54 (2005).
19. Nakamoto, H. Synchronous and Diachronous Citation Distribution (Elsevier, 1988).
20. Burnham, J. C. J. Am. Med. Assoc. 263, 1323–1329 (1990).
21. Spier, R. Trends Biotechnol. 20, 357–358 (2002).
22. Pan, R. K., Sinha, S., Kaski, K. & Saramaki, J. Sci. Rep. 2, 551 (2012).
23. Arthur, W. B. The Nature of Technology: What it is and How it Evolves (Simon and Schuster, 2009).
24. Uzzi, B., Mukherjee, S., Stringer, M. & Jones, B. Science 342, 468–472 (2013)