Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-022-01175-8 OPEN

Using network analyses to examine the extent to which and in what ways psychology is multidisciplinary

Yoshiaki Fujita[1] & Michael S. Vitevitch[1]✉

The emerging field known as the "science of science" uses a variety of quantitative techniques to (among other things) understand how a specific field changes over time. The tools of network science were used to quantify the extent to which Psychology is multidisciplinary, and how the extent to which it is multidisciplinary changed over time. Citation networks were created from all of the articles published in journals identified by the Web of Science as Multidisciplinary-Psychology for each year from 2008 to 2018. Nodes in the networks represented Multidisciplinary-Psychology journals, and connections were placed to other journals (i.e., nodes) that were cited in the Multidisciplinary-Psychology articles for each year. The citation networks showed that about 25% of the citations were to other Multidisciplinary-Psychology journals, about 50% of the citations were to Psychology journals in other sub-fields, and about 25% of the citations were to journals in other disciplines. This distribution of citations remained fairly consistent across the years examined. To identify the ways in which Psychology is multidisciplinary, clusters of nodes (known as *modules*) in each citation network were detected to identify possible research themes that were examined further with co-word networks made from the author-provided keywords in each of the Multidisciplinary-Psychology articles that appeared in each Module. Some research topics persisted in the years examined, whereas other topics were more transient. Given that multidisciplinary research did not increase over time but instead changed in areas of research focus, ways for academic and research administrators to foster and continually renew multidisciplinary research are discussed. The discussion also describes how individual researchers might use the techniques here to identify areas of research that are less commonly explored and may prove to be fruitful areas to shift their research focus. The same techniques can be used to provide insight in to other disciplines in the Humanities and Social Sciences.

[1] Department of Psychology, University of Kansas, Lawrence, USA. ✉email: mvitevit@ku.edu

Introduction

The emerging, multidisciplinary field known as the "science of science" uses a variety of quantitative techniques to (among other things) understand how a specific field or science in general changes over time, determine the factors that enable a project or research topic to succeed or fail, and identify ways to improve the process of science in general (Boyack et al., 2005; Fortunato et al., 2018; Zeng et al., 2017; Wang and Barabási, 2021). The findings from such investigations have broad implications for research policy and practice by providing academic and research administrators as well as individual scientists with information that can be used to make decisions that are evidence-based rather than based on intuition, tradition, or imperfect heuristics.

In the present review we used the tools of network science (another multidisciplinary science) to examine the extent to which Psychology is multidisciplinary, and if the extent to which Psychology is multidisciplinary has changed over time. As Psychologists we chose to focus our investigation on our own field, but the novel, quantitative techniques we employ can also be applied to other disciplines in the Humanities and Social Sciences.

We chose to assess the extent to which Psychology is multidisciplinary because there are a number of examples in the literature that demonstrate how Psychology has combined in some way one or more disciplines or fields of study to understand the mind, brain, and behavior of humans (Choi and Pak, 2006). For example, Psychology has drawn on theories from Economics to form the field that has come to be known as Behavioral Economics (Reed et al., 2013). Similarly, Psychology has drawn on theories from Biology to form the field that has come to be known as Evolutionary Psychology (Burke, 2014). Finally, cognitive psychologists have drawn from quantum theory in Physics to create quantum cognition to understand how humans make decisions under uncertain situations (Bruza et al., 2015). Other examples of Psychology drawing on other fields may also come to the reader's mind. What is missing, however, is a quantitative measure of the extent to which Psychology draws on other disciplines. By quantitatively measuring the extent to which Psychology is multidisciplinary we provide a baseline that can be used along with the techniques we describe here to determine if Psychology is more or less multidisciplinary than other disciplines.

We further chose to assess how the extent to which Psychology is multidisciplinary has changed over time because the increasing complexity and interconnectedness of social, political, and economic problems, such as climate change, make contemporary scientific problems too large for any single discipline to address on its own, necessitating an *increase* in multidisciplinary research in the future (Bruine de Bruin and Morgan, 2019; Stern, 2011). Further, "[t]he increasing complexity of science demands that concepts and methods from different disciplines be merged" (Derrick et al., 2011, p. 2). By assessing the extent to which multidisciplinary research in Psychology has changed over time we can determine if the field of Psychology has heeded the call to increase multidisciplinary research as some have advocated.

The techniques we describe here also can be used to determine if other disciplines in the Humanities and Social Sciences have increased the extent to which they engage in multidisciplinary research. Examining the extent to which other fields engage in multidisciplinary research could be useful for research and academic administrators because if a particular field has succeeded in increasing the extent to which it engages in multidisciplinary research, perhaps the incentive structures that led to increased multidisciplinary research in that discipline could be replicated in other disciplines to increase multidisciplinary research in the other disciplines as well.

We chose to use the tools of network science because a variety of disciplines have employed these tools to make novel observations that weren't possible with conventional analysis techniques (e.g., Montoya and Solé, 2002; Weeden and Cornwell, 2020), they are being used increasingly in various ways in Psychology (Borsboom and Cramer, 2013; Siew et al., 2019; Vitevitch, 2019), and they are commonly used in the science of science (e.g., Boyack et al., 2005; Fortunato et al., 2018; Zeng et al., 2017). An early example of network analysis techniques being used to study science is Price (1965), who examined a large number of published research articles. In his analysis nodes in the network represented published research articles, and links connected those articles/nodes to other articles/nodes that were cited. Among the things Price discovered was that the distribution of citations was best fit by a power-law distribution. That is, a small number of articles received a large number of citations, but many more articles received a small number of citations, and most articles received no citations at all.

In the present review we constructed and analyzed two different types of networks. One of our network analyses used an approach similar to Price (1965) because the construction of such citation networks is believed to capture the formal channel of communication among scientists, and may reveal certain characteristics of or patterns in the flow of information in the scientific community. In our present examination of Psychology, we might be able to identify which disciplines Psychology tends to draw on when engaged in multidisciplinary research. An important tenet of network science is that the pattern of connections between entities in a system influences the efficiency of processes in that system (Kleinberg, 2000; Newman, 2010), so examining the structure of citation networks may provide insights that could increase the efficiency of the formal channel of communication among scientists.

Focusing on Psychology, Xhignesse and Osgood (1967; see also Pinski and Narin, 1979) generated a citation network using 21 psychology journals to study the structure of psychology. They also noted the potential usefulness of examining trends of the citation network that emerge *over time* by comparing citation networks of different time periods (see also Sott et al., 2020). By observing changes from year to year, researchers can detect trends in a field, and can see how knowledge advances over time (see also Garfield, 1994). Therefore, in the present review a longitudinal approach was taken to examine a citation network of multidisciplinary psychology journals from 2008 to 2018. Because we started work on this project early in 2019, the year 2018 provided us with the most recent record of a complete year of published works and their citations. We reasoned that a decade (i.e., 2008–2018) should be a long enough time-span to observe changes in citation patterns, etc. Further, the span of 2008 to 2018 straddled the year 2011, when certain calls for increases in multidisciplinary research were published (e.g., Derrick et al., 2011; Stern, 2011). (We recognize that calls for increases in multidisciplinary research have been made prior to and since 2011).

The second network analysis constructed co-word networks with nodes representing author-provided keywords from each published article, and links connecting keywords that co-occurred. A similar approach was used by Ding et al. (2001) to examine research trends in the field of Information Retrieval (see also Ravikumar et al., 2015). We constructed co-word networks from the articles published in 2008 and in 2018 to examine the multidisciplinary research themes that might exist in Psychology and how those themes might have changed in that 10-year time-span. This quantitative technique can also be applied to other disciplines in the Humanities and Social Sciences to examine changes in research topics over time.

We recognize that the selection of keywords by authors is sometimes restricted to lists of keywords provided by publishers. Despite this limitation, the co-word analysis should nevertheless be informative about trends in research topics over time. This analysis may provide information about which research paths are already well-trodden, which research paths may be fruitful for future research, and which disciplines or topics might be ripe for building a new bridge between. The information provided by these two network analyses may not only be useful for individual scientists looking for new research questions, but may also be useful for policy makers and academic or research administrators to incentivize certain research topics that have much potential for growth in the near future.

Methods

Citation network. This network analysis examined peer-reviewed scientific articles published in journals from 2008 to 2018 that were registered in the Social Sciences Citation Index database of the Web of Science (WoS), and that had the subject category of "Psychology, Multidisciplinary". We reasoned that journals identified as Psychology, Multidisciplinary would provide us with an estimate of the extent to which Psychology is multidisciplinary that approached the highest value compared to Psychology journals of some other category, and Psychology journals in general.

The citation data of each of the articles published during the years 2008–2018 were extracted, and used to construct a citation network for each year. In each network, nodes represented journals, and links connected nodes when an article published in a Psychology-Multidisciplinary journal cited an article in another journal. That other journal could be another Psychology-Multidisciplinary journal (identified in Table 1 as *MultiDiscPsych*), a journal from another area of Psychology (identified in Table 1 as *Other Psych*), or a journal from another discipline (identified in Table 1 as *Other Disc*). By examining the number of times an article published in a Psychology-Multidisciplinary journal cited an article from another Psychology-Multidisciplinary journal, from a journal in another area of Psychology, or from a journal in another discipline we could quantitatively measure the extent to which Psychology draws from other disciplines (i.e., is multidisciplinary).

In the citation network for each year, nodes represented scientific journals, and links were outgoing citations from an article published in a journal identified as "Psychology, Multidisciplinary" to another journal (regardless of the subject category of the journal being cited). An outward going link was placed from a Multidisciplinary Psychology journal node, X, to another journal node, Y, if an article published in X cited an article in Y. Journals categorized as "Psychology, Multidisciplinary" could have both outgoing and incoming links (i.e., an article in one "Psychology, Multidisciplinary" journal cited an article in another "Psychology, Multidisciplinary" journal), whereas journals not categorized as "Psychology, Multidisciplinary" could have only incoming links from an article categorized as "Psychology, Multidisciplinary" that cited an article in that journal.

Because the citation network used journals not individual researchers as a proxy of the discipline that Psychology draws from when engaged in multidisciplinary research we did not distinguish if an article in a "Psychology, Multidisciplinary" journal cited an article by the same author (i.e., a self-citation) in another journal, or an article by a different author in another journal. Similarly, the geographic location of the individual researchers was not considered. Rather, the citation network focused on the level of journals because journals are often viewed as being emblematic of various disciplines.

Table 1 Number of downloaded articles, analyzed articles and journals, and citations.

Year	Downloaded articles	Analyzed articles[a]	Journals (nodes)				Citations (links)			
			MultiDisc Psych	Other Psych	Other Disc	Total	MultiDisc Psych	Other Psych	Other Disc	Total
2008	4441	4326	107 (6%)	340 (19%)	1329 (75%)	1776	19,096 (24%)	38,803 (49%)	21,248 (27%)	79147
2009	4869	4771	113 (6%)	348 (18%)	1432 (76%)	1893	22,166 (24%)	44,227 (48%)	25,520 (28%)	91,913
2010	5197	5109	113 (6%)	392 (20%)	1501 (75%)	2006	25,800 (23%)	56,245 (50%)	29,705 (27%)	111,750
2011	5828	5716	120 (6%)	409 (19%)	1646 (76%)	2175	29,671 (23%)	66,864 (51%)	34,183 (26%)	130,718
2012	6008	5861	123 (6%)	418 (19%)	1693 (76%)	2234	32,493 (23%)	73,843 (51%)	37,501 (26%)	143,837
2013	7041	6982	125 (5%)	428 (18%)	1806 (77%)	2359	37,930 (22%)	90,165 (52%)	44,753 (26%)	172,848
2014	7503	7455	124 (5%)	440 (18%)	1866 (77%)	2430	42,595 (22%)	100,676 (52%)	50,706 (26%)	193,977
2015	8988	8277	136 (5%)	449 (18%)	1958 (77%)	2543	47,532 (21%)	115,816 (52%)	57,949 (26%)	221,297
2016	9388	8667	135 (5%)	455 (17%)	2043 (78%)	2633	50,275 (21%)	124,673 (51%)	67,447 (28%)	242,395
2017	9580	8692	138 (5%)	459 (18%)	2023 (77%)	2620	51,602 (21%)	123,290 (51%)	67,783 (28%)	242,675
2018	9496	8658	132 (5%)	457 (17%)	2068 (77%)	2657	52,729 (21%)	127,736 (51%)	68,176 (27%)	248,641

MultiDiscPsych multidisciplinary psychology, *Other Psych* other psychology, *Other Disc* disciplines other than Psychology.
[a]Articles that were published in journals not registered in the Social Sciences Citation Index database of the WoS were excluded from the citation network and co-word analyses.

The open-source software Gephi (version 0.9.2) was used to analyze and visualize the data in the citation network. Various network measures (described below) were used to help identify patterns in the citation network, and to examine trends that emerged over time.

Co-word network. To identify the research themes present in the modules of Psychology, Multidisciplinary journals that were identified in the citation networks, co-word networks were constructed and analyzed. The commonly used Louvain method as implemented in Gephi was used to identify modules (i.e., nodes that tended to be more connected to each other than to nodes in another module) in the citation networks (Blondel et al. 2008; Newman and Girvan, 2004). In the co-word network, nodes were the keywords provided by the authors in each article. Links connected two keywords if they occurred together in the list of author-provided keywords. These links were not directed, but were weighted by the number of times those keywords co-occurred. Gephi was again used to analyze and visualize the data. Keywords (nodes) were filtered with a degree threshold to identify only the more important research themes of each module. To highlight only the more important research themes in the networks, and because the co-word networks varied in size the degree threshold for each network was set so that only the top 5% (or fewer) nodes and links would be visible.

Results

Citation network analysis of Multidisciplinary Psychology from 2008 to 2018. One way to quantify the extent to which Multidisciplinary Psychology is multidisciplinary is to examine if the amount of Multidisciplinary Psychology research has increased, decreased, or remained the same over time. As seen in Table 1, the number of articles published in Multidisciplinary Psychology journals approximately doubled from 4441 articles in 2008 to 9496 articles in 2018. Even when considering the slightly smaller number of articles that were registered in the Social Sciences Citation Index database of the WoS (which were used to construct the citation networks), we again see an approximate doubling in the number of articles published in Multidisciplinary Psychology journals in that time frame. One possible interpretation of this approximate doubling in the number of articles published in Multidisciplinary Psychology journals in that time frame is that there was indeed an increase in Multidisciplinary Psychology research.

However, the increase observed in the number of articles published in Multidisciplinary Psychology journals should be viewed in a broader context. It was previously observed that the number of scientific articles from a wide range of disciplines published since 1900 increased at an exponential rate, with an average doubling period of 15 years (Fortunato et al. 2018). The approximate doubling of the number of articles published in Multidisciplinary Psychology journals from 2008 to 2018 is consistent with the increased rate of publication observed by Fortunato et al. (2018) across science more broadly, and suggests that the amount of Multidisciplinary Psychology research being done relative to the overall amount of scientific research being done has instead remained approximately the same across the time period that was examined.

Another way to examine the amount of multidisciplinary Psychology research being done is to consider the number of journals classified as Multidisciplinary Psychology. In the time frame of 2008 to 2018 the number of journals classified as Multidisciplinary Psychology increased from 107 journals to 132 journals, an increase of about 25% from 2008 to 2018.

However, this increase in the number of journals classified as Multidisciplinary Psychology should again be viewed in a broader context. Mabe (2003) observed that from 1945 to 1976 the number of scientific journals increased about 4% each year, which means that the number of scientific journals in that time period would double every 16 years. Considering the Total number of journals in Table 1 we see that there were 1776 journals in 2008 and 2657 in 2018. Computing the change in the number of Total journals from year to year we find a mean value of a 4% increase from year to year, consistent with the value observed by Mabe (2003).

Consider now just the number of Multidisciplinary Psychology journals in Table 1. Here we see an increase of 107 journals in 2008 to 132 journals in 2018. Computing the change in the number of Multidisciplinary Psychology journals from year to year we find a mean value of a .6% increase from year to year. The rate of increase in Multidisciplinary Psychology journals from 2008 to 2018 is below the average increase in the number of scientific journals in general (as computed from Table 1 and observed by Mabe, 2003), and does not appear to be on the same trajectory to double in 16 years as observed by Mabe (2003) for all scientific journals from 1945 to 1976. This indicates that only a small number of Multidisciplinary Psychology journals were created (or re-classified) in this time-frame, suggesting a modest increase in the amount of Multidisciplinary Psychology research across the time period that was examined.

To quantify in another way the extent to which Multidisciplinary Psychology is multidisciplinary we examined the type of journals that were cited in Multidisciplinary Psychology articles. As seen in the columns labeled *Citations (links)* in Table 1, articles published in Multidisciplinary Psychology journals cite work from other Multidisciplinary Psychology journals (*MultiDiscPsych*) about 25% of the time, from journals in other areas of Psychology (*Other Psych*) about 50% of the time, and from journals in other disciplines (*Other Disc*) about 25% of the time. This distribution of the type of journals cited in Multidisciplinary Psychology journal articles remained roughly the same for each year from 2008 to 2018, suggesting that the extent to which Psychology is multidisciplinary has remained constant across the time period that was examined.

Analysis of co-word networks from 2008 and 2018. Although there are a variety of network measures that can be employed at the micro-, meso-, and macro-scale, the meso-scale measure of community detection (Newman, 2006; Fortunato, 2010) was used in Gephi to find *modules* or groups of journals that were more connected to each other than to other journals in the network in the citation networks from 2008 and from 2018. The Q value assesses the extent to which a network exhibits community structure (Clauset et al., 2004), with values greater than 0.3 indicating significant community structure. The stronger interconnection among certain journals/nodes would suggest that those journals share a common theme, which was further examined using a co-word network created from the author-provided keywords in each article.

In the citation network for 2008 (see Fig. 1), seven modules were detected with each module indicated by a different color in the figure. The numeric labels for each module in Fig. 1 are arbitrary. For the 2008 citation network Q value = 0.32, suggesting that the network exhibited significant community structure.

Table 2 summarizes for each module in the citation network for 2008 the number of Multidisciplinary Psychology journals, the number of other Psychology journals, the number of journals from other disciplines, and the number of citations among those

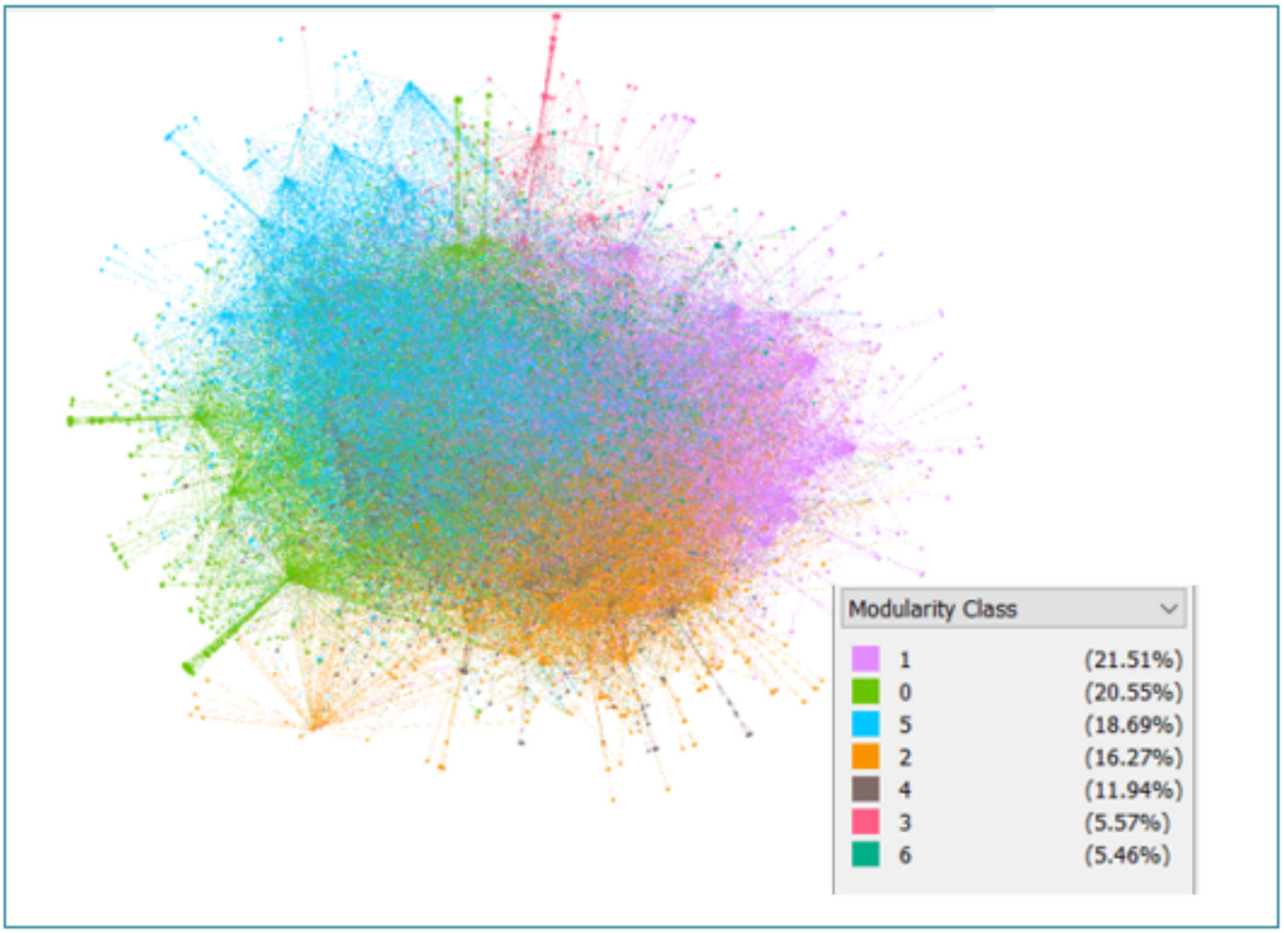


Fig. 1 Modules of the 2008 Multidisciplinary Psychology citation network. Dots are nodes representing a journal. Lines are connections between nodes indicating that an article in one journal cited an article in another journal. The different colors indicate the set of nodes that belong to a common module.

Table 2 Summary statistics for each module in the 2008 citation network.

Module	Journals (nodes)				Citations (links)			
	Multidisciplinary psychology	Other psychology	Other fields	Total	Multidisciplinary psychology	Other psychology	Other fields	Total
0	6 (2%)	30 (8%)	329 (90%)	365	1328 (18%)	1869 (25%)	3347 (57%)	7745
1	19 (5%)	69 (18%)	294 (77%)	382	3945 (17%)	8503 (37%)	10590 (46%)	21,450
2	17 (6%)	50 (17%)	222 (77%)	289	3959 (39%)	3187 (32%)	2955 (29%)	10,968
3	4 (4%)	5 (5%)	90 (91%)	99	195 (29%)	52 (8%)	435 (64%)	712
4	14 (7%)	56 (26%)	142 (67%)	212	1864 (23%)	5137 (62%)	1238 (15%)	10,820
5	39 (11%)	115 (35%)	178 (54%)	332	7376 (28%)	18109 (68%)	1175 (4%)	24,018
6	8 (8%)	15 (15%)	74 (76%)	97	429 (14%)	1946 (64%)	685 (22%)	3434

journals. Module size ranged from a group of 97 journals (Module 6) to a group of 382 journals (Module 1). There was also much variability across modules in the distribution of the type of journals that were cited by the Multidisciplinary Psychology articles in each module. The 3 most-cited journals in each module in the citation network for 2008 are listed in the Supplementary information.

In the citation network for 2018 (see Fig. 2), seven modules were again detected with each module indicated by a different color in the figure. The numeric labels for each module in Fig. 2 are arbitrary. For the 2018 citation network Q value = 0.20, suggesting that the community structure in the network while present was not as well-defined as in the 2008 citation network.

Table 3 summarizes for each module in the citation network for 2018 the number of Multidisciplinary Psychology journals, the number of other Psychology journals, the number of journals from other disciplines, and the number of citations among those journals. Module size ranged from a group of 36 journals (Module 6) to a group of 1128 journals (Module 0). There was also much variability across modules in the distribution of the type of journals that were cited by the Multidisciplinary Psychology articles in each module. The three most-cited journals in each module in the citation network for 2018 are listed in the Supplementary information.

To identify the research themes that may have contributed to the emergence of the modules in the citation networks from 2008,

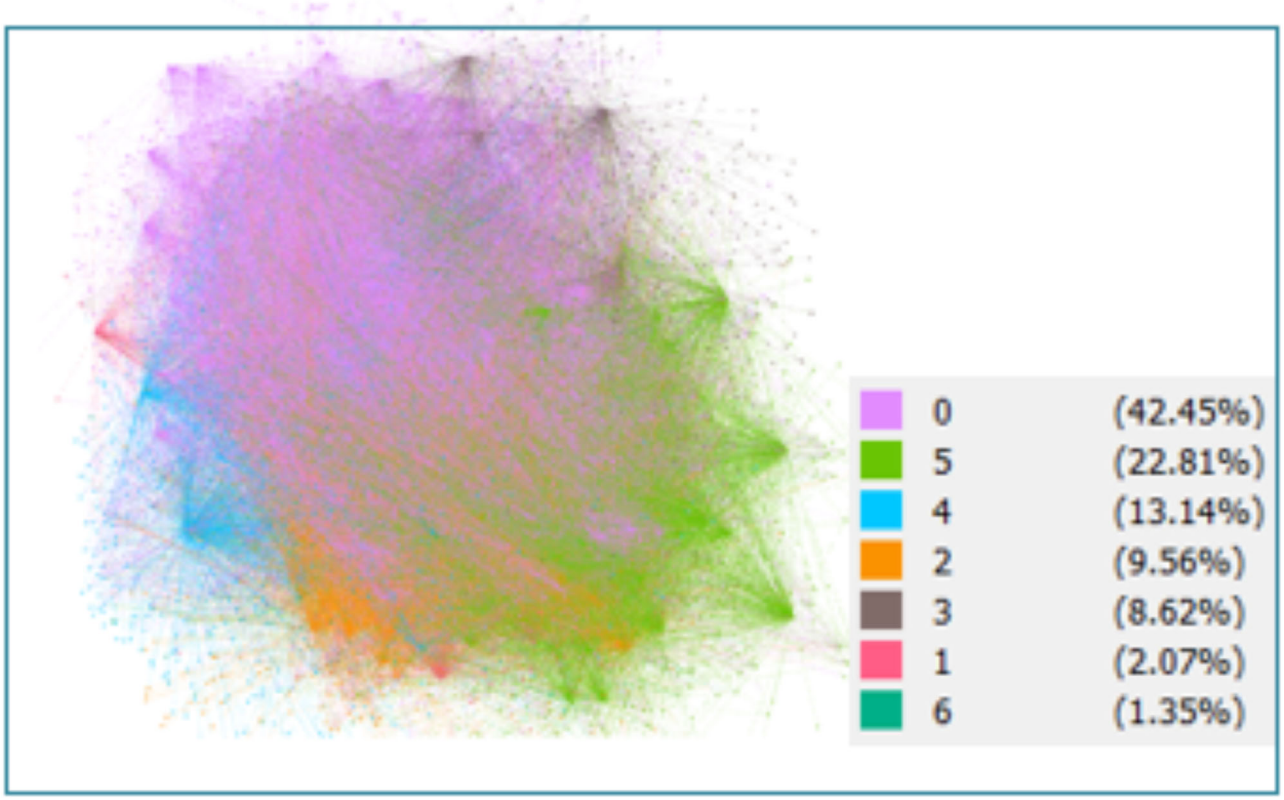


Fig. 2 Modules of the 2018 multidisciplinary psychology citation network. Dots are nodes representing a journal. Lines are connectionsbetween nodes indicating that an article in one journal cited an article in another journal. The different colors indicate the set of nodes thatbelong to a common module.

Table 3 Summary statistics for each module in the 2018 citation network.

Module	Journals (nodes)				Citations (links)			
	Multidisciplinary psychology	Other psychology	Other fields	Total	Multidisciplinary psychology	Other psychology	Other fields	Total
0	79 (7%)	345 (31%)	704 (62%)	1128	36,703 (22%)	105,716 (63%)	24,395 (15%)	166,814
1	3 (5%)	11 (20%)	41 (75%)	55	1402 (22%)	1821 (29%)	3048 (49%)	6271
2	11 (4%)	25 (10%)	218 (86%)	254	2710 (21%)	5014 (39%)	5083 (40%)	12,807
3	4 (2%)	3 (1%)	222 (97%)	229	1378 (20%)	413 (6%)	5003 (74%)	6794
4	7 (2%)	22 (6%)	320 (92%)	349	3286 (17%)	4511 (23%)	11,399 (59%)	19,196
5	26 (4%)	46 (8%)	534 (88%)	606	7065 (20%)	10,077 (28%)	19,042 (53%)	36,184
6	2 (6%)	5 (14%)	29 (81%)	36	185 (32%)	184 (32%)	206 (36%)	575

co-word networks were generated for each module (see Fig. 3). In Module 0 keywords related to computers and communication occurred frequently as indicated by the larger font size in the figure (e.g., Internet, mobile phone, and computer mediated communication). In Module 1 keywords related to mental and physical health occurred frequently as indicated by the larger font size in the figure (e.g., depression, oncology, and cancer). In Module 2 keywords related to relationships occurred frequently as indicated by the larger font size in the figure (e.g., connection, relationship, power, empathy). In Module 3 keywords related to socio-cultural psychology occurred frequently as indicated by the larger font size in the figure (e.g., culture, critical discourse analysis). In Module 4 keywords related to body-image and sexuality occurred frequently as indicated by the larger font size in the figure (e.g., body image, body dissatisfaction, homosexuality, homophobia, sexuality). In Module 5 keywords related to learning and memory occurred frequently as indicated by the larger font size in the figure (e.g., learning, memory, hippocampus, intelligence). In Module 6 keywords related to forensic psychology occurred frequently as indicated by the larger font size in the figure (e.g., violence, sex-offender, recidivism).

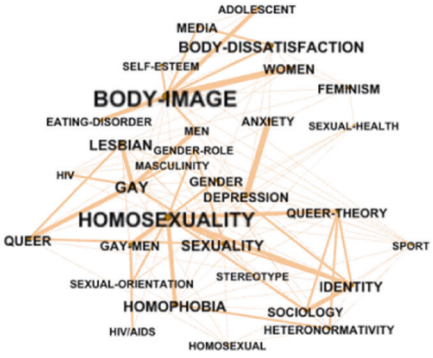
To identify the research themes that may have contributed to the emergence of the modules in the citation networks from 2018, co-word networks were generated for each module (see Fig. 4). In Module 0 a wide range of keywords related to general areas of Psychology occurred frequently as indicated by the larger font size in the figure (e.g., anxiety, motivation, personality, emotion, attention). In Module 1 keywords related to addiction occurred frequently as indicated by the larger font size in the figure (e.g., gambling, alcohol, impulsivity, depression). In Module 2 keywords related to domestic violence occurred frequently as indicated by the larger font size in the figure (e.g., intimate-partner violence, indigenous, child-sexual abuse). In Module 3 keywords related to happiness, well-being and life-satisfaction occurred frequently as indicated by the larger font size in the figure (e.g., well-being, positive-affect, job satisfaction). In Module

Themes in Module 0

Themes in Module 1

Themes in Module 2

Themes in Module 3



Themes in Module 4

Themes in Module 5

Themes in Module 6

Fig. 3 Keywords found in each module identified in the 2008 citation network. The size of the node reflects the number and weight of the degree (i.e., larger nodes had many connections and highly weighted connections). The thickness of the connection indicates the weight of the connection (i.e., connected nodes with thick lines co-occurred many times).

4 keywords related to the use of online communication occurred frequently as indicated by the larger font size in the figure (e.g., social-media, Facebook, depression, adolescent, self-esteem). In Module 5 keywords related to mental and physical health occurred frequently as indicated by the larger font size in the figure (e.g., cancer, stigma, HIV, depression, quality of life). In Module 6 keywords related to identity and discrimination towards certain identities occurred frequently as indicated by

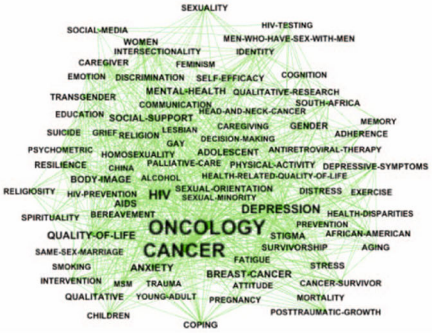
Themes in Module 0

Themes in Module 1

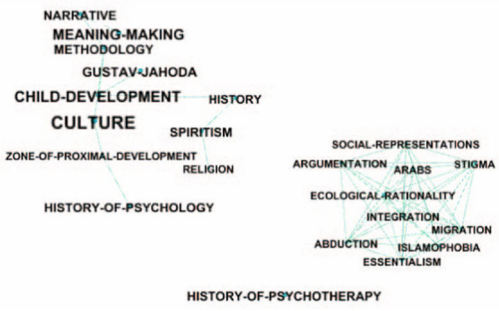
Themes in Module 2

Themes in Module 3

Themes in Module 4



Themes in Module 5



Themes in Module 6

Fig. 4 Keywords found in each module identified in the 2018 citation network. The size of the node reflects the number and weight of the degree (i.e., larger nodes had many connections and highly weighted connections). The thickness of the connection indicates the weight of the connection (i.e., connected nodes with thick lines co-occurred many times).

the larger font size in the figure (e.g., essentialism, social-representations, integration, Islamaphobia, stigma).

Discussion

In the present review a "science of science" approach was taken to examine the discipline of Psychology, and the extent to which it is multidisciplinary. The multidisciplinary tools from network science, which are increasingly being used in Psychology and commonly used in the science of science to examine citation patterns, were used to examine the citation patterns of research articles published in journals identified by WoS as Multidisciplinary Psychology from 2008 to 2018.

The results displayed in Table 1 show several interesting patterns. First, the number of articles published in Multidisciplinary Psychology journals approximately doubled from 2008 to 2018. However, the increase in the number of Multidisciplinary Psychology articles published in that time is comparable to the increase in research articles published across the sciences (Fortunato et al., 2018), suggesting that research in Multidisciplinary Psychology kept pace with the growth of science in general in the time frame examined, rather than increased or decreased compared to what might be expected in general.

Second, the number of Total journals in Table 1 from 2008 to 2018 increased approximately 4% each year; a rate comparable to other estimates of journal growth in science in general (Mabe, 2003). However, the number of Multidisciplinary Psychology journals in Table 1 from 2008 to 2018 did not increase as quickly as the number of journals in science in general, suggesting that the extent to which Psychology is multidisciplinary did not increase significantly in the years that were examined.

Third, the proportion of articles cited from other Multidisciplinary Psychology journals (~25%), from journals in Other Psychology areas (~50%), and from journals in Other Disciplines (~25%) remained fairly consistent from 2008 to 2018. One interpretation of these results is that research in Multidisciplinary Psychology journals must still be recognizable as being part of Psychology, either in the topic of the research question, the methods employed, or the techniques used to analyze the data. Research that is not recognizable as part of the discipline of Psychology may result in reviewers at Multidisciplinary Psychology journals recommending that the work instead be published in a journal of another discipline. The proportion of 75:25 may reflect the extent to which multidisciplinary research must identify with a home discipline and the extent to which such research can venture into other disciplines.

The proportion of 75:25 may also reflect the extent to which scientists seek to consolidate knowledge within their discipline to deepen our understanding of a phenomenon, versus jumping beyond current knowledge or bridging between previously unconnected clusters of knowledge (Foster et al., 2015). Alternatively, the low but fairly constant rate of citing from other fields may reflect the gradual shift of the "cutting-edge" ideas, methods, etc. initially pulled from another discipline eventually being accepted as "mainstream" Psychology, leading to the large proportion of citations to articles published within the discipline of Psychology. Unfortunately, the present data cannot distinguish among these hypotheses.

The Louvain method, a commonly used community detection algorithm (Blondel et al., 2008; Newman and Girvan, 2004), was then used in the citation networks from 2008 and 2018 to find modules of journals that were more connected to each other than to journals in other modules. Co-word networks were then created from the author-supplied keywords that appeared in the articles in each module. The analyses of the frequently occurring keywords in the co-word networks from 2008 (Fig. 3) and 2018 (Fig. 4) revealed interesting patterns about Multidisciplinary Psychology that other analysis techniques would likely not reveal. For example, certain research topics are inextricably multidisciplinary and appear to be perennial. Consider, for example the research topic "mental and physical health", which characterized Module 1 in 2008 and Module 5 in 2018. Many diseases that directly affect the physical body have psychological ramifications, such as the depression that some individuals and family members experience when managing cancer. Conversely, numerous studies have demonstrated influences of mental health on physical health and well-being (May et al., 2002). Researchers from many disciplines (e.g., medicine, nursing, psychology, social welfare, etc.) examine mental and physical health in some way, and will likely continue to do so for the foreseeable future.

The co-word networks from 2008 and 2018 also showed that certain research topics appear more ephemeral, garnering much attention at one point in time (as indicated by frequently occurring keywords), but being less prominent at another point in time (as indicated by the keywords occurring less often). The fashionable nature of certain research topics may reflect the gradual shift of cutting-edge ideas becoming more accepted by one or more discipline, therefore becoming "mainstream" and no longer a topic appearing in Multidisciplinary Psychology journals. Alternatively, the emergence and fading of certain research topics may reflect the change over time of the problems that society faces. We expect, for example, that co-word networks for publications from 2020 would reveal a module related to mental, physical, and social issues associated with COVID-19. These COVID-related topics, of course, were not problems that society faced prior to the global pandemic. Unfortunately, the present data cannot distinguish among these hypotheses.

Although it is the convention in contemporary scientific journals to discuss the implications of the observed results only for other researchers, the "science of science" approach has highlighted the importance of discussing the implications of scientific findings not just for other researchers of a given topic, but for other "consumers of science", such as administrators and politicians (both of which influence in some way the funding of science, for example), as well as the general public (who may or may not trust science, and may or may not adopt scientific recommendations, such a mask-wearing behavior during a pandemic). Given the importance of communicating to other audiences the value of the present research findings we discuss further the implications of two key findings in the present review—the percentage of work cited from other disciplines remained fairly stable from 2008 to 2018, coupled with changes in the research topics from 2008 to 2018—for academic and research administrators. Simply encouraging researchers to become *more* multidisciplinary may not be the most productive strategy in the long-term to support multidisciplinary research, because concerns about retaining one's discipline-identity may limit the extent to which a scientist can venture into another discipline (or the number of other disciplines they can venture into). Instead, academic and research administrators may be more successful in the long-term if they provide opportunities for researchers to continually build *new* multidisciplinary bridges to replace the cutting-edge connections that are absorbed into the mainstream of one or more disciplines, or that decay away as interest in that topic fades over time. Providing opportunities to create new bridges between disciplines also allows scientists to respond to new issues that emerge to challenge society.

One example of a way that academic and research administrators can foster the growth of new connections among researchers from different disciplines is to create a recurring series of short talks (i.e., 5 min in duration) that are free of discipline-specific jargon and are centered around a theme that changes with each session (e.g., Red Hot research talks; https://thecommons.ku.edu/red-hot-research). Such "lightning" talks enable researchers to see how another discipline approaches a problem, or the methods and tools that another discipline uses to address a problem, and may lead to new collaborative multidisciplinary projects. Given the challenges of engaging in collaborative research across institutions (Cummings and Kiesler, 2005), encouraging the growth of new connections among researchers within one's own institution may ultimately be most productive in the long-term. Lightning talks are, of course, only one example of how research administrators can foster the growth of new connections among researchers from different

disciplines. We recognize that this example may not be a feasible solution for all institutions given the variety of financial and other constraints that each institution faces, but research administrators in such situations should be encouraged to find other creative solutions to foster the growth of new connections among researchers from different disciplines.

In addition to providing opportunities for current scientists to engage in multidisciplinary research, academic and research administrators may consider training future scientists to engage in multidisciplinary research. Much has been written about revising for the 21st Century graduate education in STEM (National Academies of Sciences, Engineering, and Medicine, 2018). One recommendation suggests that "[i]nstitutions would provide opportunities for students to seek and develop multiple separate mentoring and advising relationships, including those that are interdisciplinary and cross departments". (National Academies of Sciences, Engineering, and Medicine, 2018, p. 130). Changing graduate education in this way to train the multidisciplinary researchers of the future is another long-term strategy that would need to be implemented at an institutional level by academic and research administrators.

Turning now to the individual researcher, the present results show that certain research topics may not be as "hot" as they once were, providing the individual researcher with some guidance about how to steer their research career going forward. The co-word networks may also provide guidance on new topics to explore in the future. For example, in Module 3 from 2018 (Fig. 4) the keywords *happiness* and *time-pressure* appear but do not co-occur often enough to be connected, suggesting that exploring how time-pressure affects happiness might be a productive line of research (Hjerm et al., 2016). Alternatively, the keywords *depression* and *adolescence* appear in Module 1 (related to addiction) and Module 4 (related to online communication) from 2018 (Fig. 4), which may motivate a researcher to explore the prevalence of depression in adolescents who might be addicted to social media (Kuss and Griffiths, 2011). Other gaps and overlaps in topics might lead to interesting new directions for an individual researcher. Further, this approach could also be used in the Humanities and other Social Sciences to identify emerging or fading research themes over time.

Although the "science of science" approach and our analyses of journal citation networks and co-word networks revealed patterns that other analysis techniques could not reveal, the present approach does have several limitations. First, as noted above, our network analyses allowed us to make several novel observations, but other techniques may still be required to distinguish among the hypotheses we proposed to account for those observations.

Second, we constructed relatively simple networks, and made only a few measures of the networks we constructed. More sophisticated networks could be constructed, for example, to include weights on the links to account for the number of times an article in journal X cited an article in journal Y. Alternatively, a type of *feature-rich network* (Interdonato et al., 2019) known as a node-attributed network could include categorical or numerical information about each node, such as the impact factor or *H* value for each journal. Work on community detection algorithms in node-attribute networks has been able to successfully detect important modules that could not be detected by network or categorical/numerical information alone (Citraro and Rossetti, 2020). Other network measures, such as various measures of centrality (Borgatti, 2005), might also provide additional insight to the citation and co-word networks described in the present review. Although we did not explore in the present review the full range of tools that network science has to offer, we believe the network science approach has much to offer researchers in the Humanities and Social Sciences.

Third, the focus in the present review on journal articles and on keywords as the units of analysis (i.e., forming the nodes in the network) is not the only way to use network science to examine the science of Psychology, or the Humanities and Social Sciences. Networks of co-authors have also been examined, with nodes representing scientists and a connection placed between nodes if those scientists were co-authors on a journal article (Ebadi and Schiffauerova, 2015). Co-author networks may provide different insights on the field, and provide information about individual scientists that cannot be provided by the present analysis using journal articles and keywords as the units of analysis.

Co-author networks may also provide an alternative way to define multidisciplinarity by considering psychologists who have published in journals in fields other than Psychology (e.g., *International Journal of Bifurcation and Chaos*; Arbesman et al., 2010), who have published articles with researchers from other fields (e.g., a computer scientist; Ferrer-i-Cancho and Vitevitch, 2018), who have published in multidisciplinary journals housed in other disciplines (e.g., *Entropy*; Siew and Vitevitch, 2020), or who have published Psychology articles using methods or statistics—such as equivalence testing—that are more often employed in other fields (Vitevitch et al., 2021). Alternatively, instead of defining multidisciplinarity at the level of individual scientists, citation networks could also define it at the level of entire disciplines. For example, one could count the number of times other disciplines cite papers published in Psychology journals, or count the number of articles published in Psychology journals that cite papers published in journals from other disciplines. Although there are alternative ways to analyze the science of Psychology, the patterns and trends observed in the network analyses that were performed in the present work have broad implications for academic and research administrators, and for individual researchers as well.

Finally, the present review only considered Multidisciplinary Psychology papers published in a 10-year window. Perhaps a longer time-span is required to observe significant growth or decline in a discipline. However, it is important to keep in mind that academic institutions create strategic plans that typically span 4- or 5-year periods. Therefore, our focus on a short time-span allowed us to make recommendations to academic and research administrators as well as to the individual researcher that are more in line with the time-frames that they typically operate on.

Network analysis is being used increasingly in a variety of disciplines in the Humanities and Social Sciences, including Psychology (Vitevitch, 2019; Cero and Witte, 2020). Seeing the application of network analyses in the present review and the insights that it can reveal may inspire individual researchers to apply this approach to their current research in the Humanities and Social Sciences to ask new and interesting questions, and to observe things that other techniques can't reveal. As demonstrated in the present review, other techniques may still be required to distinguish among the alternative hypotheses that one generates to account for the novel observations provided by network analyses, but network analysis is certainly worth adding to the methodological toolbox of researchers in the Humanities and Social Sciences.

Data availability

The data and materials reported here are available upon request.

Received: 12 November 2021; Accepted: 21 April 2022;
Published online: 12 May 2022

References

Arbesman S, Strogatz SH, Vitevitch MS (2010) The Structure Of Phonological Networks Across Multiple Languages. Int J Bifurcat Chaos 20:679–685

Blondel VD, Guillaume JL, Lambiotte R, Lefebvre E (2008) Fast unfolding of communities in large networks. J Stat Mech-Theory E 10:P1000

Borsboom D, Cramer AO (2013) Network analysis: an integrative approach to the structure of psychopathology. Annu Rev Clin Psychol 9:91–121

Boyack KW, Klavans R, Börner K (2005) Mapping the backbone of science. Scientometrics 64:351–374

Bruza PD, Wang Z, Busemeyer JR (2015) Quantum cognition: a new theoretical approach to psychology. Trends Cogn Sci 19:383–393

Bruine de Bruin W, Morgan M (2019) Reflections on an interdisciplinary collaboration to inform public understanding of climate change, mitigation, and impacts. Proc Natl Acad Sci USA 116(16):7676–7683

Burke D (2014) Why isn't everyone an evolutionary psychologist? Front Psychol 5:910. https://doi.org/10.3389/fpsyg.2014.00910

Cero I, Witte TK (2020) Assortativity of suicide-related posting on social media. Am Psychol 75:365–379

Choi BCK, Pak AWP (2006) Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. Clin Investig Med 29:351–364

Citraro S, Rossetti G (2020) Identifying and exploiting homogeneous communities in labeled networks. Appl Netw Sci 5:55

Clauset A, Newman M, Moore C (2004) Finding community structure in very large networks. Phys Rev E 70(6):066111

Cummings JN, Kiesler S (2005) Collaborative research across disciplinary and organizational boundaries. Soc Stud Sci 35(5):703–722

Derrick EG, Falk-Krzesinski HJ, Roberts MR, Olson S (2011) Facilitating interdisciplinary research and education: a practical guide. White paper reporting on the workshop "Science on FIRE: Facilitating Interdisciplinary Research and Education", held March 28–29, 2011, hosted by the American Association for the Advancement of Science and the Colorado Initiative in Molecular Biology of the University of Colorado, Boulder

Ding Y, Chowdhury G, Foo S (2001) Bibliometric cartography of information retrieval research by using co-word analysis. Comm Com Inf Sc 37(6):817–842. https://doi.org/10.1016/S0306-4573(00)00051-0

Ebadi A, Schiffauerova A (2015) How to become an important player in scientific collaboration networks? J Informetr 9:809–825

Ferrer-i-Cancho R, Vitevitch MS (2018) The origins of Zipf's meaning-frequency law. J Assoc Inf Sci Tech 69:1369–1379

Fortunato S (2010) Community detection in graphs. Phys Rep 486:75–174. https://doi.org/10.1016/j.physrep.2009.11.002

Fortunato S, Bergstrom CT, Börner K, Evans JA, Helbing D, Milojević S, Petersen AM, Radicchi F, Sinatra R, Uzzi B, Vespignani A, Waltman L, Wang D, Barabási AL (2018) Science of science. Science 359:aao0185

Foster JG, Rzhetsky A, Evans JA (2015) Tradition and innovation in scientists' research strategies. Am Sociol Rev 80:875–908

Garfield E (1994) Scientography: mapping the tracks of science. CC/Soc. Behav Sci 7(45):5–10

Hjerm M, Gärling T, Gamble A, Fors F (2016) Emotional well-being related to time pressure, impediment to goal progress, and stress-related symptoms. J Happiness Stud 17:1789–1799

Interdonato R, Atzmueller M, Gaito S, Kanawati R, Largeron C, Sala A (2019) Feature-rich networks: Going beyond complex network topologies. App Netw Sci 4:1–13

Kleinberg JM (2000) Navigation in a small world. Nature 406:845

Kuss DJ, Griffiths MD (2011) Online social networking and addiction: a review of the psychological literature. Int J Environ Res Public Health 8:3528–3552

Mabe M (2003) The growth and number of journals. Serials 16(2):191–197

May M, McCarron P, Stansfeld S, Ben-Shlomo Y, Gallacher J, Yarnell J, Davey Smith G, Elwood P, Ebrahim S (2002) Does psychological distress predict the risk of ischemic stroke and transient ischemic attack? The Caerphilly Study Stroke 33:7–12

Montoya JM, Solé RV (2002) Small world patterns in food webs. J Theor Biol 214:405–412

National Academies of Sciences, Engineering, and Medicine (2018) Graduate STEM education for the 21st century. The National Academies Press, Washington, DC

Newman MEJ (2006) Modularity and community structure in networks. Proc Natl Acad Sci USA 103:8577–8582. https://doi.org/10.1073/pnas.0601602103

Newman M (2010) Networks: an introduction. Oxford University Press, New York, NY

Newman M, Girvan M (2004) Finding and evaluating community structure in networks. Phys Rev E 69(2):026113. https://doi.org/10.1103/PhysRevE.69.026113

Pinski G, Narin F (1979) Structure of the psychological literature. J Am Soc Inform Sci 30(3):161–168. https://doi.org/10.1002/asi.4630300308

Price DJS (1965) Networks of scientific papers. Science 149:510–515

Ravikumar S, Agrahari A, Singh N (2015) Mapping the intellectual structure of scientometrics: a co-word analysis of the journal Scientometrics (2005–2010). Scientometrics 102(1):929–955. https://doi.org/10.1007/s11192-014-1402-8

Reed DD, Niileksela CR, Kaplan BA (2013) Behavioral economics: a tutorial for behavior analysts in practice. Beh Anal Pract 6:34–54. https://doi.org/10.1007/BF03391790

Siew CSQ, Vitevitch MS (2020) Investigating the influence of inverse preferential attachment on network development. Entropy 22:1029–1042

Siew CSQ, Wulff DU, Beckage NM, Kenett, YN (2019) Cognitive Network Science: a review of research on cognition through the lens of representations, processes, and dynamics. Complexity 2108423

Sott MK, Bender MS, Furstenau LB, Machado LM, Cobo MJ, Bragazzi NL (2020) 100 Years of scientific evolution of work and organizational psychology: a bibliometric network analysis from 1919 to 2019. Front Psychol 11:3411. https://doi.org/10.3389/fpsyg.2020.598676

Stern PC (2011) Contributions of psychology to limiting climate change. Am Psychol 66(4):303–314. https://doi.org/10.1037/a0023235

Vitevitch MS (ed) (2019) Network science in cognitive psychology. Routledge.

Vitevitch MS, Ng JW, Hatley E, Castro N (2021) Phonological but not semantic influences on the speech-to-song illusion Q J Exp Psychol 74:585–597

Wang D, Barabási AL (2021) The science of science. Cambridge UniversityPress

Weeden KA, Cornwell B (2020) The small-worldnetwork of college classes: Implications for epidemic spread on a university campus Sociol Sci 7:222–241

Xhignesse LV, Osgood CE (1967) Bibliographicalcitation characteristics of the psychological journal network in 1950 and in1960 Am Psychol 22(9):778–791. https://doi.org/10.1037/h0024961

Zeng A, Shen Z, Zhou J, Wu J, Fan Y, Wang Y, Stanley HE (2017) The science of science: from the perspective of complex systems. Phys Rep 714-715:1–73

Acknowledgements

We thank Jamene Brooks-Kieffer of the University of Kansas Libraries for meeting with us at the initial stage of this project, and identifying Web of Science as a potential source of data for this project. The work reported here served to partially fulfill the requirements for Departmental Honors in Psychology at the University of Kansas for YF.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors, therefore ethical approval is not applicable.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-022-01175-8.

Correspondence and requests for materials should be addressed to Michael S. Vitevitch.

Reprints and permission information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.