

Impact Assessment of a Single Study

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1 Abstract

Recent studies have focused on assessing the impact of publications using citation data. This study addresses concepts of “breadth” and “depth” and uses recently introduced metrics to quantitatively assess the breadth and depth of a single study, Paul et al. [1963]. The results of these measurements are compared against previous qualitative assessments of the network of citations to Paul et al. [1963]. Findings show that Paul et al. [1963] has breadth at the onset of publication, but deepens over the course of its lifespan, contrasting previous qualitative interpretations. It is likely that the breadth and depth metrics used in this study are better suited to distinguish publications cited for methodology from those cited for their discoveries. As such, I suggest that breadth and depth be weighted differently for methods papers and research articles to better distinguish differences in citation patterns within a single publication category.

2 Introduction

Recent studies have been interested in finding ways to assess the impact of a publication beyond simple citation counts [Bu et al., 2021, Leng, 2022]. Bu et al. [2021] propose four new metrics for measuring the impact of a research article: breadth, depth, dependence, and independence. These metrics provide more information about the impact of a given article than a standard citation count allows, as two papers can have the same number of citations but differing levels of breadth and depth or dependence and independence.

Breadth and depth measure whether papers that cite paper A also cite each other. If they do, these papers are aware of each other and are likely in the same research community. Therefore, paper A is said to have a deeper impact on a single community. If papers that cite paper A do not cite each other, they likely belong to different research communities [Bu et al., 2021]. These two metrics make up two parts of a proportion, meaning if a paper is 60% broad, then it must also be 40% deep, and vice versa.

Bu et al. [2021] provides two ways of counting breadth and depth, which the authors refer to as “relative” and “absolute.” Relative breadth and depth use ratios or percentages, like the example mentioned above. In this case, the sum of breadth and depth must be equal to one. Absolute breadth and depth are counts of nodes that fall into either category. So in the above 60:40 example, there may be 12 “broad” nodes and 8 “deep” nodes, which is the same as 60:40, just expressed as a count value rather than a ratio.

Dependence and independence have both relative and absolute values as well, but measure slightly different things than breadth and depth. A focal paper A is dependent if a paper that cites A also cites A’s references, and it is independent if the citing paper does not. The goal with these measures is to determine whether the findings of a paper are dependent on previous literature or not. Further explanation of these

terms is available in Bu et al. [2021], but I will not be using dependence and independence measures in this study (see Section 3.2).

Leng [2022] addresses similar topics to Bu et al. [2021], though the author does not use the terms “breadth” and “depth” to describe his observations. Leng [2022] discusses the story of Paul et al. [1963], a paper which reported many findings relevant to the discussion on coronary heart disease (CHD). Paul et al. [1963] is a highly cited paper, earning 445 citations within its first 21 years of publication.¹ Leng [2022] investigates how this paper was cited, a topic of interest as Paul et al. [1963] reports negative results which contradicted the leading hypothesis that dietary fat consumption was a major contributing factor to developing CHD. The weight of Leng’s [2022] analysis rests on his subjective interpretation of Paul et al.’s [1963] citing papers, which is not scalable. Given that his primary focus appears to be whether Paul et al.’s [1963] findings had a broad impact, using Bu et al.’s [2021] ideas of breadth and depth seem appropriate.

Both papers ignore how a given paper’s breadth and depth change over time. No paper is published having breadth or depth. Given the constraint of time, I hypothesize that as a given paper earns citations, this paper would be considered broad by Bu et al.’s [2021] standards, as citing papers may not necessarily be aware of each other’s work yet. Conversely, I expect any depth gained to be gained over time. Depth found immediately after publication might suggest at best, a research community deeply interested and invested in the work of other researchers or at worst, collusion on the part of the author(s).

As mentioned in Leng [2022], Paul et al. [1963] is not a particularly unique study. Paul et al. [1963] is used in this study because Leng [2022] already provides a subjective analysis of how Paul was cited, noting its diffuse impact on different areas of research within the CHD research community, rather than a profound impact on any one particular area. As this is an indicator of breadth as defined by Bu et al. [2021], this paper aims to provide evidence to either support or contradict Leng’s [2022] subjective interpretation by measuring the absolute breadth and depth of the network of Paul et al. [1963] and its citations.

3 Methods

3.1 Data

My initial approach was to take the DOIs present in Leng’s [2022] data and match them against the Open Citations database [Ope] to confirm the validity of the references to Paul et al. [1963]. The Open Citations database stores citation data in a DOI-cites-DOI format. However, nearly half of the publications present in the Leng [2022] data do not contain DOIs. This is likely because the publications in this data set were published prior to 1985 and the DOI system was first applied in 2000 [DOI]. It seems that many DOIs were not assigned retroactively, and I found it unfair to hold the data set to a modern standard in this regard. As such, I used Web of Science [Web] to locate citations to Paul et al. [1963] made between 1964 and 1984.²

This search returned 438 citations while Leng’s [2022] data contained 444 citations (both numbers exclude the Paul et al. [1963] paper itself). The seven citations present in the Leng data that were not present in the data I retrieved from WoS were manually examined to determine whether the paper cited Paul or not. Table 1 contains the citations I found in Web of Science by searching their Web of Science ID number. All

¹I am using “highly cited” here to refer to papers in the top percentile of citations received. While some of the most highly cited papers can reach hundreds of thousands of citations, the vast majority of publications earn only a handful of citations, if any. de Solla Price [1965]

²Data included herein are derived from Clarivate Web of Science, access provided through University of Illinois Urbana-Champaign. © Copyright Clarivate 2022. All rights reserved.

	Citing Paper	Citation to Paul
1	Georgiou et al. [1978]	Paul O, 1963, Coronary Heart Disea, P469
2	Hennekens et al. [1977]	Paul O, 1963, Circulation, V28
3	Freis [1973]	Paul O, 1963, Circulation, V28, P381
4	Kannel and Feinleib [1972]	Paul O, 1963, Coronary Heart Disea, P469
5	Stocksme [1972]	Paul O, 1963, Circulation, V28
6	Antonovsky [1968]	Paul C, 1963, Circulation, V28, P20
7	Hatch [1968]	Paul O, 1963, Circulation, V28, P30

Table 1: Citations present in Leng (2022) that were not returned in my own WoS search.

citations were determined to be citations to Paul et al. [1963]. I suspect these did not show up in my search due to minor formatting errors such as missing page number or typos in the name.

The citations that list “Circulation” as the source and “V28” as the volume were all determined to be references to Paul et al. [1963] as there is only one article by Paul, O. in that particular volume of Circulation. The two that list “Coronary Heart Disea” as the source were determined to be references to Paul et al. [1963] through matches to name, year, and title. Paul was the first author on two papers in 1963: “A Longitudinal Study of Coronary Heart Disease,” [Paul et al., 1963] and “Intractable Angina” Paul [1963]. As there was no mention of “Coronary Heart Disease” present in either the publication title or source title, references one and four in Table 1 were determined to be references to Paul et al. [1963].

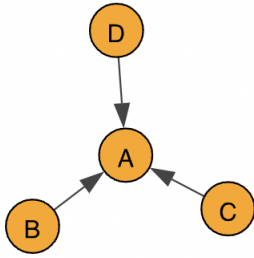
3.2 Metrics

Each paper was then evaluated according to the metrics discussed in [Bu et al., 2021]. Code to calculate these metrics was graciously provided by Moy [2022]. Table 2 describes the values calculated at a high level, but I will describe them in detail here.

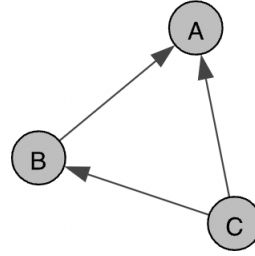
Figure 1a contains an example of a “broad” network, using A as the focal publication. Each of A’s citing papers (B, C, D) do not cite any other paper in the network. This means that A is 100% broad and has 0% depth, using the relative measurements. In absolute measurements, A’s breadth is 3 while its depth is 0. The relative measurements set breadth and depth against each other, meaning each paper is X% broad and Y% deep such that $X + Y = 100\%$. The absolute measurements are perhaps more useful when distinguishing between highly-cited and less-cited papers is important, as 100% breadth for a paper with one citation is different than a paper with 100% breadth and 100 citations.. However, since I am looking only at one focal paper and looking at how breadth and depth compare to each other for that specific paper, I will be looking at relative measures exclusively.

Another example, Figure 1b, shows paper A having 50% breadth and 50% depth. Paper A has two citing papers, B and C, one of which (B) only cites A, meaning it contributes to A’s breadth. Paper C cites both A and B, meaning it contributes to A’s depth. The ratio of breadth and depth are found by taking the number of “broad” or “deep” nodes and setting this number against the total number of citations. Therefore, one broad node to two total citations equals 50% breadth, and the same goes for depth. In this same network, Paper B has 100% depth. Its only citing paper is C, and C cites both B and A. Paper C has received no citations, so it has neither breadth nor depth. Each citing publication contributes to the focal publication’s *either* breadth or depth. It cannot contribute to both.

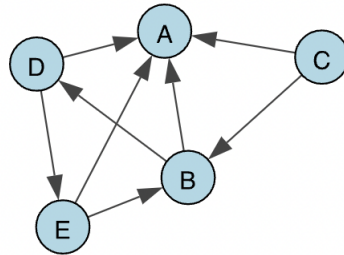
Finally, Figure 1c has 100% depth. Each of its citing nodes (B, C, D, and E) cite at least one other publication in the network that is not A. Paper A has received four citations, and has four deep nodes, so



(a) An example where focal paper A has 100% breadth. Each node in the network only cites A. B, C, nor D have any reason to cite each other.



(b) An example where focal paper A has 50% breadth and 50% depth. Node B is a broad node as it only cites A. Node C is a deep node as it cites both A and at least one other node in the network (B).



(c) An example where focal paper A has 100% depth. Each node that cites A cites at least one other paper in the network. Note that this example is unlikely in practice as there is a cycle between B, D, and E and cycles typically do not appear in citation networks.

Figure 1: Three examples of networks where paper A has varying ratios of breadth and depth.

its depth is 100%. Note that 100% depth is unlikely for a citation network such as the one used in this study where each publication cites one central paper. One instance where this *could* happen is if the citing publications also cite each other, which can happen in instances where articles are published in the same year. Alternatively, this could also occur due to collusion on the part of the authors, or shared authorship between two or more publications. However, I would expect less than 100% depth to be typical for a given citation network.

My values were calculated by finding the absolute breadth and depth for Paul et al. [1963] first and then dividing those values by the total citation count to find the relative values. To evaluate these relative values year-by-year, I ran the Bu metrics on subsets of data where each publication in the data set was published during or before 1964, 1965, 1966, etc. The final set, for example, contained all publications published during or prior to 1985 which cite Paul et al. [1963].

As mentioned previously, I chose to omit measures of dependence and independence from this study. Dependence and independence are measurements that depend on having references for each paper available in the network, and the data set for this study is specifically tailored to Paul et al. [1963] and its citing papers. Therefore, none of Paul's references are included in the data set, so measurements will state that Paul is 100% independent from the previous literature, even though this may not be the case in a greater

Bu et al. [2021] Label	My Label	Description
CP	Citation Count	Number of citations a publication has received
CP(R[citing pub] = 0)	Breadth	Number of publications that do not cite other publications in the network
CP(R[citing pub] > 0)	Depth (nodes)	Number of publications that cite other publications in the network
TR[citing pub]	Depth (edges)	Number of citations to other publications in the network
CP(R[cited pub] = 0)	Independence	Number of publications that do not cite a focal paper's references
CP(R[cited pub] > 0)	Dependence (nodes)	Number of publications that cite at least one of a focal paper's references
TR[cited pub]	Dependence (edges)	Number of citations to the focal paper's references

Table 2: High-level descriptions of the [Bu et al., 2021] metrics.

context. Additionally, references for the citing papers are not included unless these references also happen to cite Paul, so independence will be inflated while dependence is deflated. As such, these measurements were determined to have no informative value on this data, and I am focusing only on breadth and depth.

4 Results

Paul et al. [1963] was cited 444 times between 1964 and 1984, with 406 of these publications being written in English. Figure 2 shows the distribution of these citations over time. The greatest number of citations earned in a single year was thirty-one in 1967 and the lowest number was eleven, both in 1972 and 1984. As the life time of publication is approximately ten years [de Solla Price, 1965], it's unusual that Paul et al. [1963] was still earning citations in the mid-to-late 70's. However, Figure 2 shows citations to Paul et al. [1963], as well as to Kannel et al. [1964] for a point of comparison. Both papers were gaining citations as late as twenty years post-publication, and this may be typical for highly-cited papers in this particular area of research at the time.³ Regardless of why Paul et al. [1963] has a long lifespan, the paper was accumulating citations over the course of twenty years. How do breadth and depth measures change over this time span?

After the first year of publication, 75% of Paul et al.'s [1963] citing nodes are broad while 25% are deep. As Paul et al. [1963] received sixteen citations in its first year of publication, this means that twelve publications only cited Paul et al. [1963] while four cited both Paul et al. [1963] as well as at least one other node in the network. At least two of these pairs share a common author: Marquis et al. [1964] and Yudkin and Roddy [1964] share a common author as do Thomas et al. [1964a] and Thomas et al. [1964b]. One of the citing publications was cited anonymously and could not be determined to share a common author with the publication it cites. Therefore some of the citations contributing to Paul et al.'s [1963] depth this early after publication may be attributed to shared authorship, but not all can be.

Relative breadth falls below 50% in 1966, just three years after publication, and continues to decline for the remaining years. The exception to this decline is a slight uptick from 29% to 30% in 1971. As the total number of citations to Paul et al. [1963] increases, the amount of change to breadth and depth changes only slightly from year to year. Past 1967, when Paul et al. [1963] had earned ninety-three citations, changes in

³Kannel et al. [1964] was chosen as it is a highly-cited paper relevant to CHD research that was published around the same time as Paul et al. [1963]. Kannel et al. [1964] accumulated 303 citations between 1964-1974, 267 of which were written in English.

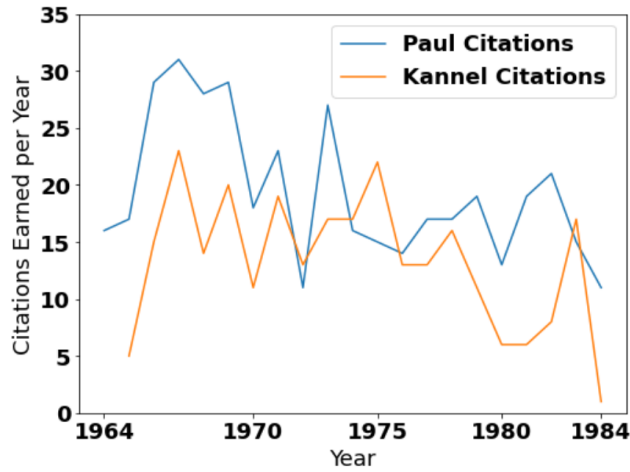


Figure 2: The number of citations Paul et al. [1963] earned each year over the first twenty years of publication, alongside Kannel et al. [1964] for comparison. Both articles are highly cited papers that pertain to CHD research and were published around the same time. Both articles were receiving citations across a twenty-year time span with a sharp decrease in citations in 1984.

Year	Total Citation Count	Citations Gained	Breadth Ratio	Depth Ratio
1964	16	+16	0.75	0.25
1965	33	+17	0.70	0.30
1966	62	+29	0.47	0.53
1967	93	+31	0.37	0.63
1968	121	+28	0.35	0.65
1969	150	+29	0.31	0.69
1970	168	+18	0.29	0.71
1971	191	+23	0.30	0.70
1972	202	+11	0.29	0.71
1973	229	+27	0.26	0.74
1974	245	+16	0.25	0.75
1975	260	+15	0.23	0.77
1976	274	+14	0.23	0.77
1977	291	+17	0.22	0.79
1978	308	+17	0.21	0.79
1979	327	+19	0.21	0.79
1980	340	+13	0.20	0.79
1981	359	+19	0.20	0.80
1982	380	+21	0.19	0.81
1983	395	+15	0.19	0.81
1984	406	+11	0.18	0.82

Table 3: Running total of citations earned by Paul et al. [1963] over the course of 20 years, the number of citations gained, the ratio of breadth and the ratio of depth for any given year from 1964-1984.

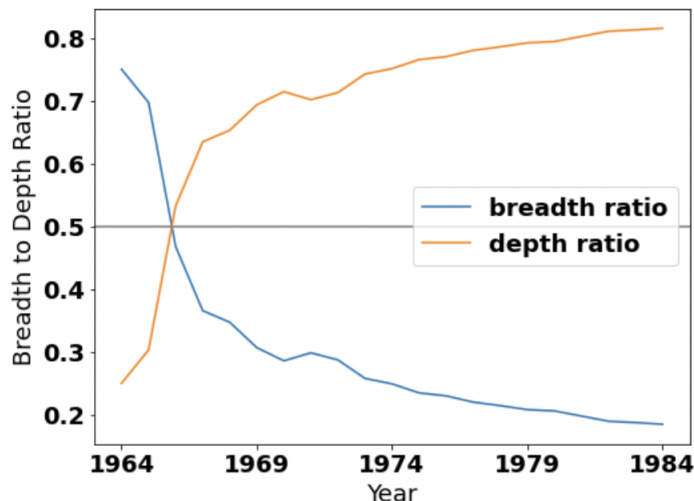


Figure 3: The ratio of citing papers classified as “broad” (blue) vs. those classified as “deep” (orange) for Paul et al. [1963]. The grey line indicates a ratio of 0.5, the point at which Paul et al. [1963] has equal breadth and depth. This point occurs around 1966, after which the ratio of depth increases over time while the ratio of breadth decreases. In the first year of publication, there are more “broad” nodes than deep ones (0.75 to 0.25). After three years, there’s nearly an even split (0.46 to 0.53), but the percentage of “deep” nodes continues to grow while the percentage of “broad” ones decreases.

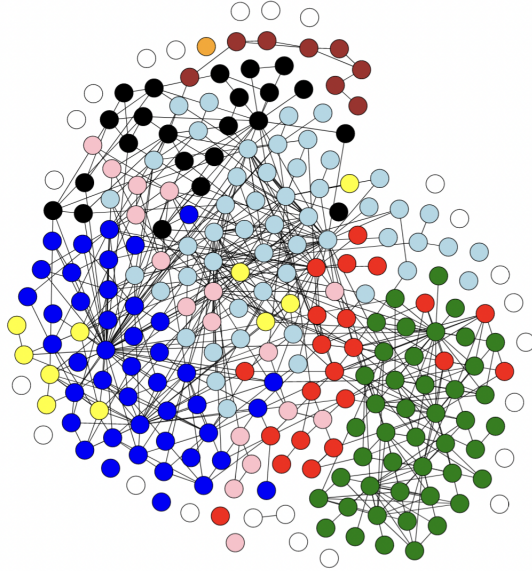
breadth and depth do not exceed four percentage points from one year to the next.

Figure 4 shows two graphs of the Paul et al. [1963] network. Figure 4a shows citation data spanning from 1964 to 1974 inclusive while figure 4b shows citation data spanning from 1975 to 1984 inclusive. Comparing these two networks, differences in topic between the two decades can be observed.⁴ The largest clusters found in the first decade pertain to serum cholesterol, blood pressure, and caffeine intake, while the largest clusters in the second decade are focused on alcohol consumption, body fatness, and diet. However, even with the topics of interest shifting over time, these topic shifts do not have a visibly noticeable impact on the overall level of breadth. On the contrary, the introduction of a new topic of interest where researchers are frequently citing each other’s work, such as the alcohol publications, may be a contributing factor to the increasing depth level as time goes on.

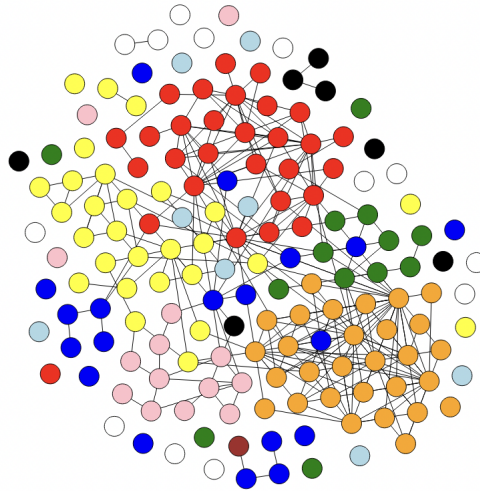
5 Discussion

After applying Bu et al.’s [2021] metrics to the Paul et al. [1963] network, the results show that the Paul network starts off as broad, but becomes a deep paper after the first 3 years of publication and continues to deepen over time. These results contradict Leng’s [2022] remarks that Paul et al. [1963] has breadth as it impacted a wide audience who took different findings and applied them to different areas of research. While it may be the case that Paul et al. [1963] impacted a broad range of research communities within the area of CHD research, Paul et al. [1963] had a deep impact on these different areas of research. Additionally, these “areas of research” as defined by clustering algorithms, which are probabilistic approximations of communities, aren’t completely isolated from each other, united only by their citations to Paul et al. [1963].

⁴Topics were extracted from Leng’s [2022] data, found in the supplementary materials in his paper. To find the clusters, Leng used the Leiden algorithm with resolution 1 to maximize the size of the clusters returned.



(a) Citation network of Paul et al. [1963] spanning years 1964-1974 (inclusive). The main topics of interest (determined by the largest clusters) during this period of time were Caffeine, Serum Cholesterol and Unspecified CHD, and Blood Pressure and Unspecified CHD. Other topics of interest include Smoking, and Psychosocial Factors.



(b) Citation network of Paul et al. [1963] spanning years 1975-1984 (inclusive). The largest clusters in the graph pertain to Alcohol, Diet, and Body Fatness and Unspecified CHD.

Figure 4: Citation graphs of Paul et al. [1963] from two different decades. The two graphs show which topics were of interest during either the first ten years of Paul et al.’s [1963] publication or the last ten years. Topics were assigned through Leng’s [2022] clustering of Paul et al. [1963] with the Leiden algorithm with resolution 1. Dark blue = Serum Cholesterol and Unspecified CHD. Light blue = Blood Pressure and Unspecified CHD. Green = Caffeine. Red = Diet. Yellow = Body Fatness and Unspecified CHD. Pink = Physical Activity. Orange = Alcohol. Black = Psychosocial Factors. Brown = Smoking. White = Undefined.

There are connections between clusters, indicating inter-community awareness of each other’s research. Even if a “smoking” paper cites a “diet” paper only to argue against its findings, the two are still participating in the same conversation. It may be true that Paul et al. [1963] is “broader” than similar papers that report fewer findings, but this remains to be determined. As it stands, Paul et al. [1963] is a deeper paper than Leng [2022] reports. Because this is a qualitative analysis, Leng [2022] may be focusing more on the differences between the papers in the network than the similarities between them, resulting in over-reporting breadth.

However, the way that Bu et al. [2021] measures breadth means that highly-cited discovery papers are unlikely to be considered broad, as the authors’ criteria for breadth seem tailored towards describing how tool and methods papers are cited. Is it really true that a research article could never be considered “broad?” I believe that the Bu metrics under-report breadth as the criteria for a paper to be considered broad are quite strict. Perhaps the criteria were developed to distinguish the contributions of methods papers and label them as categorically distinct from research articles. As methods papers tend to be cited based on the methodologies or tools they offer, citing papers are unlikely to have much in common with each other. Conversely, research articles are generally cited based on their discoveries, which tend to be specific to a single area of research. Therefore, it seems that the criteria for breadth and depth were created to distinguish between these two categories, but if so, Bu et al. [2021] does not mention this.

Was either Leng [2022] or Bu et al. [2021] correct? I believe that the Bu et al. [2021] metrics over-estimated depth and Leng [2022] over-estimated breadth. The breadth and depth metrics presented in Bu et al. [2021] evaluate a given paper based on their context within a tailored network, which is not necessarily a fair way to evaluate a paper. Data can be very easily tailored such that Paul et al. [1963] might be considered by some to have breadth within a network focused on CHD, for example, but the same paper might be considered to have depth in a larger network that focused on, for example, medicine. If the network includes much more data, the bar for breadth becomes much, much higher, to the point I am skeptical that any research article could be considered “broad” by Bu et al.’s [2021] standards, simply due to the expectation that research builds on the discoveries of others.

Leng [2022] hypothesizes that Paul et al. [1963] will have greater breadth than other papers because of the multitude of findings reported. The current study is insufficient to determine whether this is true or not, as no other papers were analyzed in a similar fashion to Paul et al. [1963] to form a basis for comparison. Paul et al. [1963] has a greater proportion of depth to breadth by far, but is this any more or less than other papers show?

However, Paul et al. [1963] stood out to Leng [2022] as a paper deemed worthy of investigating due to this perceived breadth, which may indicate that while Paul et al. [1963] is considered deep by the Bu et al. [2021] metrics, it may be broader than other research articles. This possibility was not addressed in this study, but may be a topic of interest for further research. I suggest that when examining whether a research article is broad or deep, the breadth criteria be weighted. This would allow there to be both broad and deep methods papers as well as broad and deep discovery papers, rather than breadth and depth being a cover term for methods papers versus discovery papers.

Another point to consider is that a paper’s breadth and depth are more meaningful with the accumulation of more citations. In the early days of publication, a paper hasn’t had the time to accumulate very many citations and new additions to the network create greater fluctuations in the breadth or depth measurements. For example, if a paper has 10 citations, each citation represents 10% of its breadth or depth. If a paper has 100 citations, each citation only represents 1% of its breadth or depth, so the introduction of new publications have less power to cause fluctuations in the overall breadth or depth. Note that as stated earlier, two or

more citation pairs present in the first year of Paul et al.’s [1963] publication were instances of self-citation, causing the depth to increase in this first year. Depth may change depending on the timing and frequency of self-citation, something future research may want to consider. However, instances of self-citation have more influence over the relative proportion of depth when there are fewer citations overall.

6 Conclusion

This study has so far avoided the question of what the goal of impact assessment is or should be. For some, Bu et al.’s [2021] might be sufficient as these metrics provide a very low-grade distinction between methods papers and discovery papers. These researchers might be asking “Was this paper cited for its methodologies or for its discoveries?” If so, the metrics Bu et al. [2021] propose may be sufficient.

Some researchers, like Leng, might like the option to measure the breadth of a discovery paper compared not to the set of all publications, but to other discovery papers specifically. In this case, different criteria may be needed to avoid over-categorizing these papers as deep. Weighting discovery articles differently to allow a more lenient measure of breadth, for example, could be one way to distinguish broad and deep research articles. Paul et al. [1963] may or may not be broader than other, similar research articles in CHD literature, but it is unlikely to be broad compared to all medical literature. Determining whether there is any meaningful difference in breadth and depth for highly cited articles within a research community is an opportunity for further research.

I believe that at a high level, Bu et al. [2021] and Leng [2022] are interested in the same concepts of breadth and depth. Their definitions of these concepts, however, are slightly different and require different lenses. Bu et al.’s [2021] metric for breadth is so strict that I suspect only tool and methods papers could be categorized as broad. On the other hand, Leng’s [2022] interpretation of Paul et al. [1963] is subjective and prone to human biases such as creating categories for the information available, even if such categories are not necessary. Leng’s [2022] interpretation would benefit from quantitative support that can be replicated and applied to other, similar networks for comparison. However, the Bu et al. [2021] metrics, as they stand currently, do not offer an appropriate resolution necessary to answer Leng’s [2022] question.

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