Measuring the quality of scientific references in Wikipedia: an analysis of more than 80M citations to over 800,000 scientific articles

Joshua M. Nicholson, Ashish Uppala, Matthias Sieber, Peter Grabitz, Milo Mordaunt, Sean Rife

Address correspondence to: Joshua M. Nicholson, PhD, scite Inc., 2 N 6th St, #31A, Brooklyn, NY 11249, USA

Email: josh@scite.ai

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Abstract: Wikipedia is a widely used online reference work which cites hundreds of thousands of scientific articles across its entries. The quality of these citations has not been previously measured, and such measurements have a bearing on the reliability and quality of the scientific portions of this reference work. Using a novel technique, a massive database of qualitatively described citations, and machine learning algorithms, we analyzed 1,923,575 Wikipedia articles which cited a total of 841,821 scientific articles, and found that most cited articles (58%) are uncited or untested by subsequent studies, while the remainder show a wide variability in contradicting or supporting evidence (2-40%).

Wikipedia, the free online encyclopedia, is an integral part of the web and society. With over 18 billion visits per month, currently ranking it as the 10th most visited website in the world, it has become the go-to source of information for nearly all aspects of life. It is comprised of over 6M articles and 49M pages, which have received 934M edits from 38M users. Because Wikipedia is so important for maintaining a well-informed society, we sought to determine how primary research articles informing Wikipedia articles have been cited within the scientific community.

As of 2018, there were 841,821 scientific articles in Wikipedia referenced across 1,923,575 Wikipedia articles, meaning 32% (1,923,575/6,006,758) of all Wikipedia articles reference a scientific article. The accuracy of these articles is paramount, especially considering that Wikipedia is often the first and only source of information for some readers. The task is delegated to its large community of volunteer editors and users; claims are heavily debated and calls for primary sources of evidence are flagged with the now popular phrase: "Citation Needed." But just how reliable are these sources?

To answer this question, we performed a citation analysis of scientific articles referenced on Wikipedia using “Smart Citation” data from scite. Smart citations provide the context for each citation and a classification describing whether it provides supporting or contradicting evidence for the cited claim. Classifications are performed by a deep learning model that has been trained on 43,665 expert-labeled citation

statements with precision scores of 0.800 0.8519, and 0.9615 for supporting, contradicting, and mentioning classifications, respectively (internal scite benchmarking data). To date, scite has analyzed over 15M full-text scientific articles, extracting over 500M citation statements that cite over 34M articles. These scientific articles were obtained through a variety of means, including retrieval of open access papers, preprints, PubMed Central, and through partnerships with various publishers.

Using this information, we analyzed the 841,821 scientific articles referenced in Wikipedia to see how they had been cited in the scientific literature. These articles have received 87,953,427 total Smart Citations according to scite. Of those, 2,594,738 (2.95%) indicate that they provide supporting evidence, 315,930 (.36%) indicate that they provide contradicting evidence, and 85,042,687 (96.7%) mention the citing study without indicating that they provide supporting or contradicting evidence. Wikipedia articles referencing scientific articles cited 2.44 (SD = 24.09) scientific articles on average. This figure differs slightly from a recent estimate likely due to variations in data collection (Arroyo-Machado et al. utilized Altmetric data in their analyses, while we used data retrieved directly from Wikipedia) [1]. Among scientific articles referenced by Wikipedia articles, the average number of citing articles was 75.64 (SD=261.10), the mean number of supporting citations was 2.37 (SD=6.34), the mean number of contradicting citations was .32 (SD=1.02), and the mean number of mentioning citations was 72.96 (SD=257.06) (Table 1). The most cited scientific article referenced in Wikipedia describes Laemmli buffer, which is widely used in protein analysis and has

over 62k citation statements [2]. Most articles (337,182/841,821, 40.05%) remain untested by other subsequent citing articles (no supporting or contradicting cites), 155,263 (18.44%) have no citations at all, 230,761 (27.41%) have been supported with no contradicting evidence, 103,328 (12.27%) have been disputed with both supporting and contradicting evidence, and 15,287 (1.82%) have been contradicted with no supporting cites. 297 scientific papers referenced by Wikipedia articles have been retracted; however, the vast majority of these references are recognized as retracted in the text of the Wikipedia article itself (for example, the Wakefield et al. [3] paper presenting evidence of a causal link between vaccines and autism is frequently cited as part of a discredited body of research).

Our results should be considered with caution given the limitations of the model precision, the current limited coverage of articles analyzed by scite, and that articles without DOIs or identifiable DOIs in the data set were excluded. Beyond technical limitations, it is also important to consider what the citation classifications mean. For example, a contradicting citation statement does not necessarily mean the cited paper is wrong because: 1) scite classifies citation statements at the level of the claim, not the full paper, and 2) the citing article making the contradicting claim itself could be without merit. Nonetheless, these numbers are a good approximation of how the scientific foundations of Wikipedia have been tested in the scientific literature and represent the first time an analysis of the quality of citations, not just the quantity, has been done at this scale. Previous citation analyses at the individual article level have shown that

reporting the citation context can be informative for readers [4][5] with one citation analysis [5] causing the publisher to add the following warning to the original report [6], *"Editor's Note (added May 31, 2017): For reasons of public health, readers should be aware that this letter has been "heavily and uncritically cited" as evidence that addiction is rare with opioid therapy."*

To look at how citation context could impact Wikipedia users if it were linked next to scientific references, we examined a handful of articles directly. The Wikipedia article on "Amygdala" states, *"In 2006, researchers observed hyperactivity in the amygdala when patients were shown threatening faces or confronted with frightening situations. Patients with severe social phobia showed a correlation with increased response in the amygdala"* citing Phan et al. [7] as evidence for this statement. According to scite [8], this reference has received 226 mentioning citation statements, 23 supporting citation statements, and 2 contradicting citation statements (Figure 2). Thus, while some have provided supporting evidence, two studies have called this into question, with one report stating [9], *"These findings do not replicate previous studies..."* The citation context offers more than just a complete picture; it potentially affects decisions by everyday readers. Consider the Wikipedia article "Suicide and Internet" which features the following statement, *"A survey has found that suicide-risk individuals who went online for suicide-related purposes, compared with online users who did not, reported greater suicide-risk symptoms, were less likely to seek help and perceived less social support,"* highlighting a report by Harris, McLean, and Sheffield [10]. As identified by scite [11],

this report was later contradicted by a subsequent study finding that suicide-related Internet use individuals were more likely to seek help [12] (Figure 3). Providing contextual citation information for this Wikipedia article could influence behavioral choices that have potentially life or death consequences for a large population of people.

In conclusion, Wikipedia for the most part references scientific articles that are supported or untested with a minority being contradicted, similar to what has been seen in other citation network analyses [13]. When Wikipedia articles cite scientific papers that have been subsequently contradicted (or even retracted), this is usually explicitly stated, and often in service of a larger conversation about the article itself. However, citations alone fail to capture the tenuous nature of scientific claims. Making the citation context available to moderators and readers is critical to reliably evaluating scientific claims. We suggest the adage “Citation Needed” is not enough. References in Wikipedia as well as scientific articles themselves should display citation contexts. Platforms and publishers like Europe PMC and Wiley are starting to adopt this approach and technology and we think this could be helpful for Wikipedia as well.

Table 1. Citation Breakdown of Scientific Articles Referenced in Wikipedia

Classification	**Mean (SD)**
Total citations	75.64 (261.10)
Mentioning citations	72.96 (257.06)
Supporting citations	2.37 (6.34)
Contradicting citations	0.32 (1.02)

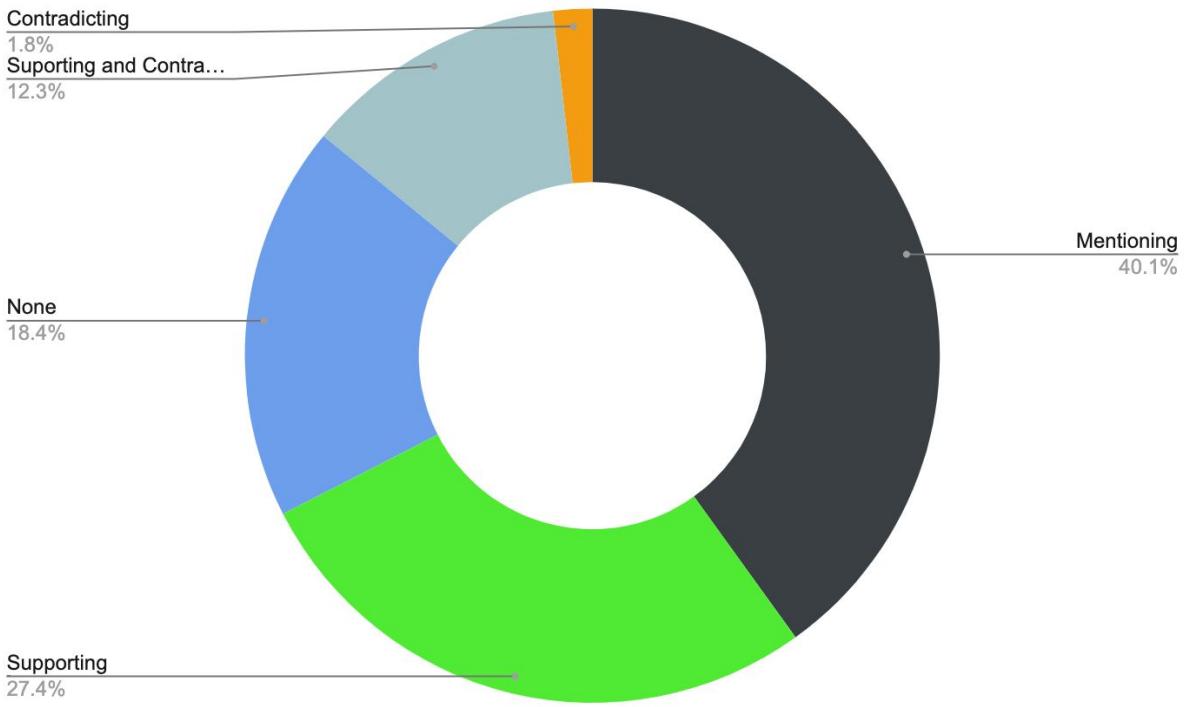

Figure 1. Overview of how scientific articles referenced in Wikipedia articles have been cited within the scientific literature. Most articles (337,182/841,821, 40.05%) have received only mentioning citations, 230,761 (27.41%) have received a supporting citation with no contradicting evidence, 155,263 (18.44%) have received no citations, 103,328 (12.27%) have received both supporting and contradicting citations, and 15,287 (1.82%) have received contradicting citations.

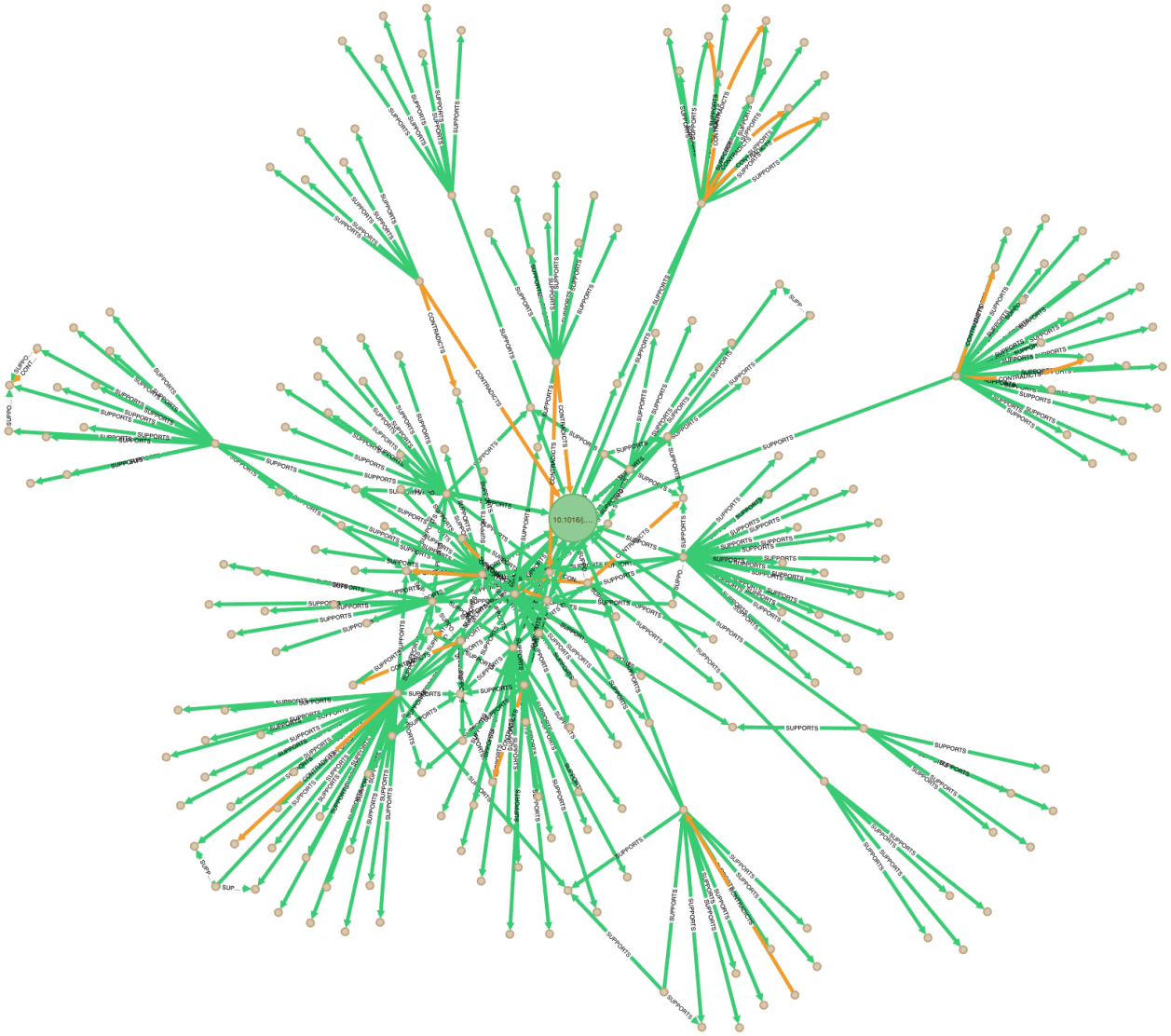

Figure 2. Citation visualization of Phan et. al [7] showing only supporting and contradicting citations. Green lines indicate supporting citations and orange lines indicate contradicting citations. Citation network shows two levels removed from the target citation.

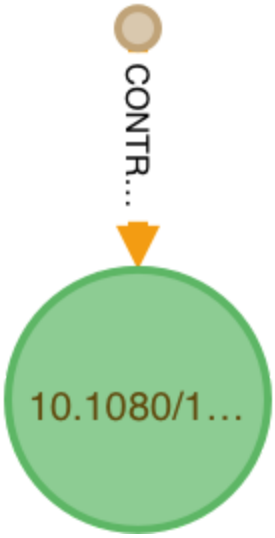

Figure 3. Citation visualization of Harris, McLean, and Sheffield [10] showing the single contradicting citation it has received (no supporting citations).

Methods Supplement

Identification research articles in Wikipedia

We used data previously scraped from Wikipedia [14] containing a list of citations with their identifiers from Wikipedia content dumps published on March 1, 2018. The data fields included the *id* and *type,* such as “pmid” for PubMed ID, “pmcid” for PubMed Central ID, and “doi” for Digital Object Identifier. First, we mapped all identifiers to DOIs using mapping data from the PMC metadata database (https://www.ncbi.nlm.nih.gov/pmc/pmctopmid/), which provides links between PMIDs, PMCIDs, and DOIs. Mapped DOIs were combined with DOIs where the identifier type was designated “doi” and were considered valid if the DOI existed in a dataset of all known DOIs provided by CrossRef. Within the scraped data, 96% of entries were successfully linked to a DOI, and among those DOIs, 98% were valid. Given a valid DOI, it was possible to query against our internal citation data to determine how frequently it was cited, supported, mentioned, or contradicted.

Citation analysis

Citation analyses were performed by querying internal scite citation data. Descriptive analyses and graph generation were performed in R. All queries and code can be found at https://github.com/scitedotai/research-wikipedia.

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