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Untangle the Characteristics of Disruptive and Consolidating Citations of Nobel-winning Papers

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ABSTRACT
Scientific breakthroughs have the potential to revolutionize the course of research and shape the trajectory of scientific knowledge. This study investigates the characteristics of Disruptive Citing Papers (DCP) and Consolidating Citing Papers (CCP) associated with Nobel-winning scientific breakthroughs, aiming to provide insights into the mechanisms of knowledge creation and dissemination. By analyzing a dataset of Nobel-winning papers and their citation networks, we find that Nobel-winning papers tend to attract a higher proportion of DCP compared to CCP. However, CCP exhibit a higher impact, as evidenced by their citation counts and likelihood of becoming hit papers. Furthermore, DCP are associated with larger research teams, highlighting the collaborative nature of disruptive research, while CCP employ a higher degree of professional language style characterized by shorter titles and specialized jargon. These findings deepen our understanding of the role played by disruptive and consolidating impact in scientific breakthroughs, shedding light on the dynamics of knowledge creation and dissemination in the scientific community. This research contributes to the broader understanding of scientific progress and provides valuable insights for researchers, policymakers, and stakeholders in the scientific ecosystem.

KEYWORDS
Science of Science; Disruption; Consolidation; Nobel-winning Papers; Citation Networks.

INTRODUCTION
Recent contributions by Funk et al. (2017), Wu et al. (2019), and Park et al. (2023) have introduced a novel approach to quantifying the disruptive nature of papers, offering valuable insights into disruptive citing patterns. By examining the underlying structure of deep citation networks, these studies have introduced the Consolidation-Disruption (CD) index, which evaluates the extent to which patents and scientific papers consolidate or disrupt existing trends or disciplinary fields (Azoulay, 2019). These indices enable the quantification of research impact by new researchers and categorization of scientific research impact into two dimensions: disruptive impact and consolidating impact (Bu et al., 2021; Chen et al., 2021; Lin et al., 2022). Disruptive Citing Papers (DCP) encompass papers that cite the focal paper but do not reference the focal paper's cited references. On the other hand, Consolidating Citing Papers (CCP) include papers that not only cite the focal paper but also reference at least one of the focal paper's cited references. By examining DCP and CCP separately, a more comprehensive understanding of the role played by disruptive and consolidating impact in scientific research can be attained.

Despite the widespread use of disruptive and consolidating impact concepts across various fields (Bornmann & Tekles, 2021; Leydesdorff & Bornmann, 2021; Ruan et al., 2021; Wang et al., 2023), the differences between DCP and CCP of scientific breakthroughs have not been adequately discussed. Therefore, this study aims to address this gap by examining the difference between DCP and CCP of scientific breakthroughs represented by Nobel-winning papers. This analysis is expected to provide insights into the mechanisms of knowledge creation and dissemination and offer a more complete understanding of the role of disruptive and consolidating impact in scientific research.

This study aims to examine the characteristics of the DCP and CCP of scientific papers, particularly Nobel-winning papers. To achieve this objective, the research questions guiding this investigation are as follows:

1. To what extent do Nobel-winning papers attract Disruptive Citing Papers (DCP) compared to Consolidating Citing Papers (CCP), and how does this balance of DCP and CCP contribute to the impact of the scientific breakthroughs?
2. What are the disparities in the impact exhibited by DCP and CCP of Nobel-winning papers, and how do these disparities relate to the intrinsic disruptive and consolidating nature that characterizes scientific breakthroughs?
3. How do variances in team size and linguistic features manifest between DCP and CCP of Nobel-winning papers, and how do these variances influence the overarching disruptive and consolidating impact of scientific breakthroughs?

METHODOLOGY
This paper builds upon the existing disruptive and consolidating impact methodology (Funk & Owen-Smith, 2017; Leydesdorff & Bornmann, 2021; Park et al., 2023; Wu et al., 2019; Yang et al., 2023), to propose a novel approach that divides the citations of a focal publication into two categories: disruptive and consolidating citations. As shown in Fig. 1A, a focal paper (FP) in the citation network, along with its reference set $R = \{r_1, r_2, \cdots, r_m\}$ and citation set

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$C = \{c_1, c_2, \cdots, c_n\}$, form a coherent knowledge flow sub-network that provides deep citation information about the forward and backward central nodes in the citation network. To explore the implicit relationships among articles, the citation set of R is also considered, denoted as $RC = \{rc_1, rc_2, \cdots, rc_k\}$. Notably, nodes in RC may include more nodes as they point to multiple articles. Thus, the consolidating citation can be represented as $CC = RC \bigcap C$, and the disruptive citation can be represented as $DC = C - CC$.

This approach allows for the division of citing papers into two categories: Disruptive Citing Papers (DCP) and Consolidating Citing Papers (CCP). Subsequently, we can quantitatively assess the temporal structure of the dual impact exerted by the disruptive and Consolidating Citing Papers, respectively. To illustrate this methodology, we select an exemplary paper, "Ordering, metastability and phase transitions in two-dimensional systems" (Kosterlitz & Thouless, 1973), which received the Nobel Prize in Physics in 2016. Fig. 1B-C demonstrates the dynamic patterns of DCP and CCP within the citation network of this paper. As the citation network evolves over time, new citation links can be categorized as either disruptive or consolidating, depending on whether they connect to the references cited by the focal paper. At the initial stages, CCP may dominate the citation network, while over time, DCP may gain prominence.

RESULTS

The impact of Nobel-winning scientific breakthroughs on both the scientific community and society at large holds immense significance. To provide a comprehensive evaluation of the impact of these breakthroughs, we employ citation analysis to delve into the characteristics of two distinct types of citing papers: Disruptive Citing Papers (DCP) and Consolidating Citing Papers (CCP) in the context of Nobel-winning scientific breakthroughs. Utilizing the Microsoft Academic Graph (MAG) dataset, we extracted all forward and backward citation links associated with Nobel-winning papers, resulting in a dataset comprising 1,124,254 citing papers. Among these, a substantial proportion of 940,250 (83.6%) are categorized as Disruptive Citing Papers (DCP), while 184,004 (16.4%) are identified as Consolidating Citing Papers (CCP).

Given the log-normal distribution exhibited by the citation-based data (Peterson et al., 2010), we employed the Mann-Whitney U test and Kolmogorov-Smirnov (K-S) test to examine the differences between DCP and CCP in each field (Li et al., 2020). As depicted in Fig. 2, the results are highly revealing, demonstrating that the average number of DCP for Nobel-winning papers is significantly higher than that of CCP in the fields of Physics (p-values < 0.001), Chemistry (p-values < 0.001), and Medicine (p-values < 0.001), respectively. This finding posits that Nobel-winning papers tend to attract a greater number of DCP than CCP. DCP represents citing papers that challenge established ideas and facilitate paradigm shifts, whereas CCP build upon existing knowledge and refine established paradigms. Given that Nobel-winning papers often embody groundbreaking and avant-garde research that disrupts established paradigms and fields, it is unsurprising that they are more likely to attract DCP than CCP.

Our measure of impact is the citation counts each paper receives, which has been shown to correlate with research quality (Waltman, 2016; Wang et al., 2013). Our results, as depicted in Fig. 3, provide empirical support for the second hypothesis formulated in this study. The average citation counts for citing papers in Physics are 32.4 (DCP) and 49.4 (CCP) (p value < 0.001), in Chemistry are 45.4 (DCP) and 68.8 (CCP) (p value < 0.001), and in Medicine are 49.7 (DCP) and 68.0 (CCP) (p value < 0.001), supporting that DCP receive more citations than CCP. To address the potential bias arising from the citation window (Wang, 2013), we further analyzed the 10-year citation counts (Sinatra et al., 2016) for both DCP and CCP. The average 10-year citation counts for citing papers in Physics are 24.1 (DCP) and 33.4 (CCP) (p value < 0.001), in Chemistry are 29.5 (DCP) and 40.9 (CCP) (p value < 0.001), and in Medicine are 33.1 (DCP) and 44.3 (CCP) (p value < 0.001). Additionally, we examined the average citation counts that excluded zero-cited papers (Fig. 3D), as well as the probability of becoming zero-cited papers (Fig. 3E). Our analysis reveals that the average citation counts, excluding zero-cited papers, are significantly higher for DCP compared to CCP. Furthermore, DCP also exhibit a higher likelihood of becoming zero-cited papers in each respective field.

Moreover, to assess the robustness of result regarding the higher impact of CCP compared to DCP, we conducted an analysis of their probability to become hit papers. Hit papers are defined as those receiving the top 1% highest citations within their specific subfield and publishing year, representing recognized achievements in the scientific community (M. Y. Wang et al., 2020). The results, depicted in Fig. 4, consistently demonstrate that CCP are more likely to become hit papers. In Physics, the probability of CCP becoming hit papers is 4.3%, whereas for DCP it is 3.3%. Similarly, in Chemistry, the probability of CCP becoming hit papers is 4.9%, while for DCP it is 3.1%. In Medicine, the probability of CCP becoming hit papers is 5.6%, compared to 3.9% for DCP. These findings indicate that CCP have a higher likelihood of achieving hit status compared to DCP.

Finally, in order to investigate the disparities in team sizes between DCP and CCP associated with Nobel-winning papers, we conducted a rigorous analysis. The outcomes, depicted in Fig. 5A-B, suggesting that CCP are associated with smaller research teams compared to DCP. Specifically, in the field of Physics, the average team size for citing

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papers related to Nobel-winning scientific breakthroughs is 11.1 (DCP) and 4.9 (CCP) (p values < 0.001). In Chemistry, the average team size is 4.1 (DCP) and 3.7 (CCP) (p values < 0.001), while in Medicine, it is 3.9 (DCP) and 3.6 (CCP) (p values < 0.001). These findings suggest that the disruptive nature of DCP in the context of Nobel-winning papers necessitates the involvement of larger teams capable of harnessing diverse expertise, resources, and perspectives to challenge established paradigms and propel scientific progress. In contrast, CCP, which emphasize consolidating and refining existing knowledge, may require smaller team sizes to efficiently build upon pre-existing breakthroughs. By examining the team sizes associated with DCP and CCP, we gain valuable insights into the collaborative dynamics and knowledge generation processes underlying Nobel-winning scientific breakthroughs.

FIGURES

All figures in this paper are stored at https://github.com/AlexJieYang/Figures-for-ASIST2023-POSTER .

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