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A comparison of two approaches for measuring interdisciplinary research output: The disciplinary diversity of authors vs the disciplinary diversity of the reference list

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A R T I C L E   I N F O

A B S T R A C T

This study investigates the convergence of two bibliometric approaches to the measurement of interdisciplinary research: one based on analyzing disciplinary diversity in the reference list of publications, the other based on the disciplinary diversity of authors of publications. In particular we measure the variety, balance, disparity and integrated diversity index of, respectively, single-author, multi-author single-field, and multi-author multi-field publications. We find that, in general, the diversity of the reference list grows with the number of fields reflected in a paper's authors' list and, to a lesser extent, with the number of authors being equal the number of fields. Further, we find that when fields belonging to different disciplines are reflected in the authors' list, the disparity in the reference list is higher than in the case of fields belonging to the same discipline. However, this general tendency varies across disciplines, and noticeable exceptions are found at individual paper level.

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1. Introduction

The possibility of scientific and social gain through interdisciplinary research (IDR) is of increasing interest to both academics and policymakers. Among many sources, the importance of this theme is attested by the data reported in the US NSF's 2016 Science and Engineering Indicators (National Science Board, 2016). Continuing the pattern of previous years, in 2014, around 2% of total federal U.S. spending for academic R&D in science and engineering was allocated to interdisciplinary or multidisciplinary research, not to a specific field. Additionally, within U.S. higher education, national survey data continues to show a tendency towards knowledge integration from multiple disciplines. Between 2004 and 2013, universities responding to the NSF's annual Higher Education Research and Development Survey reported steady growth in R&D spanning more than one field of science and engineering, and 40% of respondents to the NSF's Survey of Earned Doctorates[1] in 2013 reported two or more dissertation research fields, up from 24% in 2001.

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[1] https://www.nsf.gov/statistics/srvydoctorates/#tabs-1. Last accessed 30 July, 2018.

Although present research policies often implicitly assume that IDR can be readily identified and tracked, this is far from true. Providing policymakers with measures and analyses that capture the intensity of IDR and knowledge integration is a scientific task of high practical importance, yet it is fraught with difficulties – see Wagner et al. (2011) and Rousseau, Zhang, and Hu, (2018) for a review. In this work, we focus on the issues associated with measuring IDR. More precisely, we investigate the convergence of two bibliometric approaches to measurement: one based on analyzing disciplinary diversity in the reference lists of publications (Mugabushaka, Kyriakou, & Papazoglou, 2016; Porter, Cohen, Roessner, & Perreault, 2007; Rafols & Meyer, 2010; Wang, Thijs, & Glänzel, 2015; Zhang, Rousseau, & Glänzel, 2016), referred to as the reference list method in the following; the other based on the disciplinary diversity of a publication's authors (Abramo, D'Angelo, & Di Costa, 2012; Schummer, 2004), referred to as the authors method in the following. Measuring IDR has important benefits: among others, learning more about the collaboration behaviour of scientists, informing policies and initiatives aimed at fostering IDR, as well as monitoring its trends to assess the efficacy of policies.

The paper is organized as follows. After an overview of the literature on the subject, in Section 3 we present the field of observation and the way we apply the two methods to measure IDR: the authors method and the reference list method. In Section 4 we illustrate the results of the analysis, and in Section 5 we draw our conclusions.

2. Literature review

Despite a growing attention to IDR by many scholars, there are still challenges on various fronts. Among them, developing a conceptual and practical definition of IDR, and indicators and methods to measure IDR (Huutoniemi, Klein, Bruun, & Hukkinen, 2010).

IDR can mean different things to different people. According to the Committee on the Science of Team Science et al. (National Academies Press, 2005), interdisciplinary research is: "A mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice." In this definition, the key concept is knowledge integration. The more an article, or any other item under investigation, integrates sources from different disciplines, the more it is interdisciplinary. The sources could be information, data, techniques, tools, perspectives, concepts, etc.

In general, the literature classifies research activity involving experts of different disciplines as belonging to three principal categories: multidisciplinary, interdisciplinary, and transdisciplinary research (OECD, 1998). Stokols et al. (2003) provide a brief and precise distinction, as follows. "Multidisciplinary" research occurs when researchers from different disciplines work independently and sequentially, each from his or her own discipline-specific perspective, to address a common problem. In "interdisciplinary" research, researchers work jointly, but from the perspective of each of their respective disciplines to address a common problem. In "transdisciplinary" research, researchers work jointly to develop and use a shared conceptual framework that draws discipline-specific theories, concepts, and methods together to address a common problem. Choi and Pak (2006) contrast the different definitions of multidisciplinary, interdisciplinary, and transdisciplinary research in the literature. They find that the three terms are used to refer to a continuum of increasing levels of involvement by multiple disciplines. Multidisciplinarity sits at the base, where different disciplines work on the same problem in parallel, or sequentially, to move beyond the confines of their own field. Interdisciplinarity follows, where each discipline interacts reciprocally. Reaching this level requires a "loosening" of the disciplinary confines to generate new methodologies, knowledge, or even new shared disciplines. Finally, at the transdisciplinary level, each discipline transcends its traditional confines and examines the dynamics of entire systems from a holistic point of view. Although the distinctions between each of the above terms are valuable, evidence of the continuum found in empirical studies can often make it difficult to distinguish which is which (Rafols & Meyer, 2010). According to a review by Klein (2008), each of these three types of "disciplinarity" is also characterized by a particular type of "knowledge integration", meaning a particular mode of merging theories and concepts, techniques and tools, or information and data from various fields of knowledge. In this paper, we use the term interdisciplinary (interdisciplinarity) in a more general sense to encompass multi-, trans-disciplinary research on the individual paper level.

However subtle and sophisticated these distinctions between the different modes of integrating knowledge might be, in the end, one has to face the reality of measuring such "knowledge integration" and the challenges they presents. It seems not recommendable to define a unique and absolute measure of IDR. Hence, scholars have developed a variety of proxy indicators, each one delivering different insights about the interdisciplinary nature of the research under study. It is, therefore, unsurprising that these different indicators sometimes deliver inconsistent and even contradictory results. Adams, Loach, and Szomszor, (2016) point out that it is essential to consider a framework for analysis that draws on multiple indicators rather than expecting any simplistic index to produce an informative outcome on its own.

A review of the literature reveals that measuring IDR has typically been conducted through either field-based research and surveys (Palmer, 1999; Qin, Lancaster, & Allen, 1997; Sanz-Menéndez, Bordons, & Zulueta, 2001) or through quantitative measures within a bibliometric approach or social network analysis (Schummer, 2004). Wagner et al. (2011) provide a full review of studies on the different approaches to understanding and measuring IDR, finding that bibliometric measures, such as co-authorships, co-inventors, collaborations, references, citations, and co-citations, are the most frequently studied and used. It is worth noting that bibliometric methods are not capable of discriminating among multidisciplinarity, interdisci-