Various aspects of interdisciplinarity in research and how to quantify and measure those

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Abstract

Interdisciplinary research figures high on today's policy agendas. This short introduction and overview sketches the complexity of defining and mapping the nature of interdisciplinary research (IDR). The paper focuses on the different approaches to IDR and different methods applied in bibliometric studies that allow measuring it. These methods should not only be able to capture quantitative aspects of IDR but also to monitor evolutionary aspects and help answer the question of whether IDR stimulates collaboration and results in larger impact and visibility. Two specific indicators, variety and disparity, are developed, validated and applied to bibliometric data. They enable the visualization of the interdisciplinary nature of research activities at various levels of analysis (both institutional and individual). And, given the longitudinal character of bibliometric data and databases, both indicators allow for mapping time-dependent phenomena and evolutions. Relevant examples based on the literature and recent results from research conducted at the Leuven bibliometrics group of ECOOM (e.g., Glänzel et al., 2021; Huang et al., 2021) are given, and concrete proposals for future research are articulated.

Keywords: Interdisciplinary research, knowledge integration, scientific collaboration, citation impact

1. Introduction

Interdisciplinarity in scientific research can be considered a result but also a remedy for the increasing complexity and urgency of current scientific and societal tasks and challenges (Wang et al., 2015). Interdisciplinarity emerges, among others, through the coalescence of scientific, technological and social processes and their requirements manifest in different forms. The common characteristics of these forms of *interdisciplinary research* (IDR) can show different facets such as in methodology or the fields of applications. In particular, the ideas and approaches needed for new scientific discoveries and their technological implementation serving to speed up the solutions of social problems often exceed the scope of specialised subject fields (Ledford 2015). This has just clearly been described by the National Academies (COSEPUP, 2004):

> "*Interdisciplinarity 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 specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice*."

According to the above definition, knowledge integration is the essence of IDR. This knowledge integration can occur at different levels. Quite often, we focus on the team level or organizational level. This level, though, tends to overlook the importance of interdisciplinary science at the individual level. The mind of the scientist often is a fertile locus of interdisciplinary work. The scientific career of Max Delbrück, an astronomer – theoretical physicist, who embarked upon biophysics and biology, became a founding father of the new discipline of molecular biology and went on to win a Nobel Prize in medicine, stands out as a premier case of interdisciplinary science at the individual level. (Strauss, 2019)

Beside individual and institutional level dynamics, interdisciplinary science also contributes to the structural dynamics of science in general. Building further on the Max Delbrück case, integration processes can be observed whereby interdisciplinary work in time turns into new disciplines. The origin of molecular biology implied intense interdisciplinary exchanges. Molecular biology has turned into a paradigmatic science and its contributors are no longer considered interdisciplinary. Individual pioneers were able to amalgamate knowledge spanning from different domains into a completely new discipline, even into a completely new biology paradigm. (Mazzocchi, 2019)

Furthermore, the emergence of interdisciplinary topics is always characterised by specific *cognitive processes*, independently of the form in which IDR appears. Interdisciplinarity can, for instance, emerge from an overarching idea or concept (e.g., nanotechnology), from the complexity of applications of a breakthrough discovery (e.g., fullerenes), from economic and societal consequences of scientific and technological achievements and their industrial implementation (e.g., global warming) or from the conscious combination of methods from different, otherwise not related subjects, to solve specific problems (e.g., biomedical engineering). The need for and significance of interdisciplinary research is recognised by both researchers and science policy already for decades. In particular, various policy and funding initiatives have been developed to encourage interdisciplinary research (Wang and Shapira, 2015). The European Union issued "Quest for Interdisciplinary Research" for the European Research Area and Horizon 2020 (Allmendinger, 2015).

The world two biggest funding organisations, the US National Science Foundation (NSF) and the National Natural Science Foundation of China (NSFC), too, give high priority to financing IDR (Zhang et al, 2018). While funding organisations consider interdisciplinarity rather from the viewpoint of possible application and its benefit to other disciplines, scientists focus more on the intra-scientific aspects, i.e. the cognitive aspects and scientific collaboration. At the same time, also scientific background, skills, curiosity, search behaviour and knowledge of the researchers play another important part in solving interdisciplinary tasks. These aspects form the basis of the two different approaches to bibliometric studies of IDR that will be studied in the following sections to show how valid metrics for measuring interdisciplinarity can be developed. In particular, we will develop and plot bibliometric research of interdisciplinarity along the following six paths.

1. Conceptualisation: perspectives and approaches (Section 2)
2. Basic concepts of modelling (Section 3)
3. The cognitive approach (Section 4)
4. Subject classification and granularity level (Section 5)
5. Quantification and measurement (Section 6)
6. Further perspectives: Interdisciplinarity and citation impact (Section 7)

The first section will be devoted to introduce and briefly discuss the most important perspectives and general approaches to IDR Studies.

2. Conceptualisation: Perspectives and Approaches

This first section gives an introduction into the conceptualisation of interdisciplinarity embracing the various *approaches* to IDR, the *delineation* from related topics, its *concepts* as well as the *bibliometric and mathematical methods* developed and applied to quantify and measure interdisciplinarity. This comprises, in particular, the framework within which we conceive and position our notion of IDR in the process of knowledge creation and scholarly as well as broader scientific communication, and of how we can delineate IDR from other related concepts.

There is still a certain lack of objective consensus in the literature as to the definition of *interdisciplinary* (Huutoniemi et al., 2010). The definition of interdisciplinarity is, of course, closely related to conception of what we consider a "discipline" and discussions of the varieties of interdisciplinary, multidisciplinary and transdisciplinary research have occupied much scholarly debate (cf. Choi and Pak, 2006). Wickson et al. (2006) proposed the key characteristic in transdisciplinary research are problem focus, evolving methodology and collaboration. Although both researchers and science politicians make a distinction between the terms interdisciplinary, multidisciplinary, transdisciplinary and cross-disciplinary research (Stokols et al., 2003; Wickson et al., 2006), in empirical studies we rather find a continuum with fuzzy borderlines and even overlaps, which makes it difficult to draw clearly determined borderlines (Rafols and Meyer, 2010). We can only consider multidisciplinary as a separate term as it has characteristics that distinguishes it from the other related terms. Multidisciplinarity is particularly a characteristic of research at higher levels of aggregation as it is based on a sum of activities manifested by document sets or projects and research output of individual scientists, published in journals, proceedings, book series and research activities of institutions. Choi and Pak (2006) have given an exhaustive overview of the above modes. According to them, multidisciplinarity is to be considered a not integrative juxtaposition of disciplines without challenging disciplinary boundaries (cf. Klein, 1990). Although Choi and Pak draw upon several other literature sources, all of these have in common that "*Interdisciplinarity is a synthesis of two or more disciplines, establishing a new level of discourse and integration of knowledge"* (Choi and Pak, 2006), while transdisciplinarity transcends the boundaries of disciplines and research in a holistic manner. Transdisciplinarity may be viewed as an extended form of interdisciplinarity that goes across, beyond, and over disciplinary boundaries and may integrate non-scientific sources as well (Choi and Pak, 2006; Flinterman et al, 2001).

Porter et al. (2007), have further specified several forms of which knowledge can be shared and integrated without the requirement of the formation of teams. These are by

- ideas (such as concepts and theories),
- methods (techniques and tools), and/or
- data from various fields of knowledge.

It is generally accepted that the main characteristic of IDR is the integration of knowledge from different disciplines, provided that we have any notion what the term discipline stands for. This immediately implies that we have first to clarify, what we consider a discipline and what structures of disciplines we have to consider. According to Fanelli & Glänzel (2013), disciplines are formed on the basis of common cognitive characteristics and general approaches in the main branches of science, linked to the hierarchy of the sciences. This directly leads to cognitive and organisational structures in the classification of the domains, fields and topics of scientific and technological research activities. A further but closely related step is to understand how knowledge integration may actually be implemented and how this is manifested in the body of scholarly knowledge. Once this is clarified, we can choose an appropriate concept for studying interdisciplinary research and develop the necessary bibliometric and mathematical tools to process available data, to quantify and measure those aspects of IDR we intend to analyse.

Table 1 A researcher's topic in four differently structured classification frameworks

Classification framework	Identification basis	Manifestation
Professional qualification	education	e.g., curriculum vitae
Organisational	employment	e.g., institutional affiliation
Administrative	funding	e.g., project, grant application
Cognitive	research	various outputs (publications, patents)

One of the traditional manifestations of IDR is research collaboration of scientists from different disciplines, in particular the integrative collaboration of several disciplines is the recurring main theme in the literature review provided by Choi and Pak (2006). However, the ambiguity of the disciplinary assignment of research has repeatedly been pointed to, among others, by Glänzel et al. (2016), in the context of data integration. Instead of redrawing Figure 5 in the original article, we summarise an overview in Table 1 showing how IDR can be implemented by researchers with whom and with whose activities the disciplines can be associated. It is self-evident that a researcher may have different disciplinary assignments within these frameworks. As a consequence, collaboration among scientists from different fields may be an important manifestation of interdisciplinary research, but is not a necessary requirement of IDR as interdisciplinary can be realised by a single individual researcher alone, if, for instance, skills, affiliation and research represent different fields of research, as highlighted by the Max Delbrück case. We just mention in passing that the lack of concordance between the subject classifications across the four frameworks makes the disciplinary assignment rather difficult, if those frameworks are to be used simultaneously.

From a policy perspective mission- and program-oriented imperatives have gained increasing importance. This imperative is translated in the mechanisms designed to fund research. Funders can play a catalytic role in encouraging interdisciplinary research by setting and articulating "grand challenges" objectives that require interdisciplinary approaches (cognitive and organizational). As a consequence, certain programs or projects are "born interdisciplinary". This is reflected in their architecture and setup (review mechanisms, reporting mechanisms, work packages, coordination packages, funding structure, etc.). For instance, in its response to the British Academy's call for evidence on interdisciplinarity (2015), the Royal Society (2016) argues:

> "*Many of the major challenges that society faces today will require solutions developed through interdisciplinary research and cross-disciplinary collaboration. Improving support for and addressing the barriers to this work could contribute to major scientific breakthroughs at the interface of disciplines, develop new technologies and ultimately support the economy and develop novel solutions to societal challenges*".

Another important initiative is the Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE), which has been launched to support bold interdisciplinary projects in all NSF-supported areas of science, engineering, and educational research (cf. NSF, 2013). In particular,

> *"INSPIRE will help to break down any disciplinary barriers that may exist within NSF and encourage its program managers to use new tools, collaboration modes and techniques in the merit-review process to widen the pool of prospective discoveries that may be hidden from or circumvented by traditional means."*

The two main bibliometric approaches to interdisciplinarity studies

Rafols and Meyer (2010) developed a framework for the bibliometric research of interdisciplinarity, where IDR is interpreted from the viewpoint of knowledge integration. Recently, bibliometric research of IDR is relying on the following two distinct foundational concepts.

1. The *cognitive approach* is based on information flows (e.g., Porter et al., 2006; Leydesdorff and Rafols, 2011; Zhang et al., 2016).

2. The *organisational approach* analyses collaboration and co-authorship on the basis of the researcher's affiliation and subject classification (e.g., Abramo et al., 2012). This may be a combination of two of the before-mentioned fours aspects: organizational affiliation and professional qualification (cf. Table 1).

The *cognitive approach* is above all analysing information flows on the basis of cited references. This information science related model is also the practically most elaborated subtopic of IDR-bibliometrics. The basic idea behind this approach is that IDR is reflected by the use of information from different and not necessarily related topics in a new cognitive environment and context. The advantage of this approach is that the information flow is "frozen" in the light of references. The other way around, namely the use of information in different topics in the light of citing papers is also promising, all the more, because this is suited to capture the dynamics of knowledge transfer as well. Citation-based (cited or citing) measures of number of topics (variety), their distribution (balance) and disparity express the extent as well as the important cognitive characteristics of interdisciplinarity (cf. Zhang et al., 2016; Wang et al., 2015). Both the definition of what a discipline is (cf. COSEPUP, 2004) and the granularity of a classification scheme are of paramount importance for the quality of metrics and the validity of results (cf. Zhang et al., 2016). The cognitive approach can also be extended by lexical analyses. For instance, Natural Language Processing allows the measurement of the cognitive distance of documents or parts of documents (Rousseau et al, 2017). This is useful above all in disciplines of the social sciences and humanities, where citations are less frequent and thus less suited for the measurement of information flows. Building similar measures of variety, balance and disparity is, of course, possible in the textual approach as well.

The *organisational model* proceeds from the assumption that IDR is manifested in the collaboration of scientists with different educational background and professional experience. In this approach, all researchers are assigned to (unique) disciplines (Abramo et al., 2012). On the larger scale, this approach can be augmented by author affiliation as well. More recently, bibliometricians are experimenting with a combination of the two approaches (Zhang et al., 2018), which can be considered a *hybrid* solution. A further extension can be obtained from the combination with the interdisciplinarity in technology (Ko, Yoon & Seo, 2018). Science-technology linkage (Dou, 2017) can serve as the cognitive basis of this approach. This is possible by using citation links between scientific publications and patents (Lan, Katrenko & Pan, 2015) and the co-activity and collaboration of authors/inventors (Magerman et al, 2015).

The two approaches require different methods and techniques of data mining and subject-assignment, but the fundamental methodological questions regarding the choice of the granularity level, subject classification and delineation, assignment of research to disciplines, and quantification and metrics may remain the same.

Important questions to be answered by future research are the harmonisation of the underlying concepts in order to obtain (nearly) identically structured data and consequently commensurable and valid measures of interdisciplinarity. Although these approaches require different methods and techniques of data mining and subject-assignment, the main general methodological questions (granularity choice, subject delineation, quantification and metrics) may remain the same tasks and may use the same or similar techniques. Subject classification and its granularity form only one, however, very important issue in all approaches. The (mathematical) combination or, alternatively, the interpretation of indicators originated from different approaches and thus reflecting different aspects of IDR will remain the final challenge in this context.

3. Two basic concepts in IDR studies

According to the state of the art in bibliometric research, there are two main concepts in quantitative IDR studies, called *diversity* and *coherence*.

1. Diversity

This is one of the central concepts related to IDR. According to Stirling (1994), diversity has three specific components: *variety*, *balance*, and *disparity*. The variety corresponds to the question of 'how many disciplines are integrated', while balance gives an answer to the question of 'to what extent these disciplines are involved' Those two questions imply that variety and balance are closely related. Both are concerned with the number and weight of disciplines involved, but they are not targeted at their relationship with each other. The only information required for variety and balance is how many different things are observed and how observations are distributed. It is quite obvious that a situation with large but ill-balanced variety, that is, many disciplines involved skewed distribution, may practically be considered similar to a situation, where only few disciplines of similar weight are integrated.

Unlike the first two components, the third one, disparity, digs somewhat deeper into the disciplinary structure of research: This component attempts to search for an answer to the question of 'how different from each other the involved disciplines are'.

This concept requires the existence of an a-priori subject classification system as this forms a top-down approach. A further requirement is de determination of its granularity level since we can and have to decide here, whether we analyze IDR at the field, discipline or topic level.

On the basis of the above definitions, a clear reference is given for the quantification and measurement of these components although no concrete algorithms and formula are proposed. This has been done, e.g., by Stirling (2007), who proposed specific indicators for each component of diversity and an integrated indicator (usually referred to as *Rao-Stirling* diversity measure). We will come back to these measures again later on, namely in the section on quantification and measurement of interdisciplinarity.

2. Coherence

The second important concept related to interdisciplinarity is coherence, which has been much less considered in IDR studies than diversity. Rafols and Meyer (2010) proposed that for studying knowledge integration, both diversity and coherence must be considered. According to Rafols and Meyer coherence expresses "*the extent that specific topics, concepts,* *tools, data, etc. used in a research process are related*". The term diversity thus relates to cognitive heterogeneity, while coherence relates to a process in which previously different and disconnected bodies of research become related. In a nutshell, diversity in this context is a disciplinary characteristic, while coherence is a network property. If both components are combined, the following four possible constellations can be observed.

- Low diversity and high coherence: knowledge integrated from the same discipline while the topics/sources are highly related (specialised disciplinary research).
- Low diversity and low coherence: knowledge integrated from different research topics within the same discipline (topic interdisciplinarity).
- High diversity and high coherence: knowledge originated from many but similar disciplines (no new knowledge integration).
- High diversity and low coherence: knowledge originated from many disciplines that were hitherto unrelated (potentially new knowledge integration).

Rafols and Meyer (2010) suggest that the combination of these two approaches may be useful for comparative studies of emergent scientific and technological fields where new and controversial categorizations are accompanied by equally contested claims of novelty and interdisciplinarity. Rafols (2014) further proposes to subdivide the concept of coherence into the three aspects: density, intensity and disparity.

Here, we should also note that, unlike the diversity concept, coherence does not require a pre-defined subject classification scheme as it is based on a bottom-up network approach.

The two concepts, *diversity* and *coherence* can, of course, be operationalized within different contexts, both from the cognitive and the organizational perspectives.

4. The cognitive approach

In the course of the rather short history of quantitative IDR studies, two basic perspectives, namely the cognitive and the organisational approach, have been established in bibliometric research. Our preferred approach is the cognitive one. There are several reasons resulting from theoretical and practical advantages, for taking this decision. The cognitive perspective or approach proceeds from the interpretation of knowledge integration as information flow. In other words, this approach analyses how information is passed from one discipline to another and how it becomes integrated in joint research results. This approach has two fundamental requirements:

- Data availability, that is, large multi-disciplinary bibliographic databases form an ideal global platform for IDR studies offering the opportunity to benchmark across countries and research fields.
- Standardised data sources are required for the necessary subject assignment and the quantification of knowledge integration in the mirror of information flows.

The necessary data integration and the IDR-intensity measurements can preferably be solved using the cognitive approach. This approach furthermore allows the elaboration of the most detailed and finetuned solutions for studying the following aspects of IDR. Although the cognitive approach mainly proceeds from studying information flows reflected by citation links, analyses can be extended to the following three aspects.

1. Collaboration of researchers active in different disciplines, where authors of individual documents can be linked to disciplinary subjects on the basis of their subject profiles.
2. Information flow has two directions, which allows the analysis of two main aspects, namely the integration of knowledge as reflected by cited references, and the knowledge

diffusion in the sense of use of information from (mono-)disciplinary research in different other disciplines.

3. Tracing knowledge integration and diffusion through analysing lexical characteristics and text similarity of documents.

These three options make the cognitive perspective a versatile approach to bibliometric studies of interdisciplinarity. Taking a broader view, interdisciplinarity further has to be understood as a process. This becomes clear if one looks at the second direction of knowledge diffusion mentioned in point 2 of the above list, in addition to the snapshot provided by the reference or affiliation list in the document. That implies, that the effect and the scope of interdisciplinarity may change over time as can be reflected either by the subjects of future citations or the field assignment of authors citing the document under study. This also implies that interdisciplinarity might (only) become manifest beyond the time frames in which the data are frozen by the study's measurement scope and that an important aspect of IDR is closely related to future citation impact on other subjects. The same phenomenon applies to both concepts of diversity and coherence. Nonetheless, evaluative studies will remain restricted to base their reports on time-bound snapshots of this process reflecting the situation around the time of data collection and analysis.

It is quite obvious that the cognitive approach has to be applied at the lowest level of aggregation, i.e., at the level of individual documents or projects in order to be able to distinguish between knowledge integration (interdisciplinarity) and juxtaposition (multi-disciplinarity). The detailed implementation of the cognitive approach will be discussed in the section on quantification and measurement, but before doing so we have to deal with the use of subject classification systems and the appropriate granularity level to be chosen for the IDR studies.

5. Subject classification and granularity level

Independently from any subject classification underlying the definition of disciplines for IDR studies, the questions arise at what level one wishes to study knowledge integration and of how actors and research could be assigned to those disciplines. In the process of granularity choice and disciplinary assignment, we are faced by the notorious demons to measurement "that frustrate our efforts to gain understanding by empirical investigation" (Bookstein, 1997). The main issues are ambiguity and fuzziness and, again, those are manifested at several dimensions. From the *conceptual* viewpoint, one has to decide whether field or topic interdisciplinarity or some kind of combination of both is to be considered. The applied bibliometric method used for detecting knowledge integration and the determination of subject (dis-)similarity result in a further increase of ambiguity. The fuzziness of borderlines at lower granularity level with cognitively overlapping subjects, on the one hand, and inconclusive (not unique) multiple-assignment at higher granularity resolution, on the other hand, forms the *cognitive* dimension. The *quantitative* dimension is a result of quantification and measurement, in particular, of the proposed and applied indicators of IDR themselves. All these dimensions have, however, in common that subject classification and its granularity level strongly build on how disciplines are defined and delineated. The implementation of an appropriate model should, therefore, preferably be based upon a conceptual, however, quantitatively supported solution. We mention in passing, that on the conceptual side, the choice of a higher granularity, allows the distinction between interdisciplinarity at the global (i.e., across all subjects) and local (i.e., within a given discipline) level.

Bibliometric groundwork for subject identification and assignment – The granularity level

In order to see how the above-mentioned considerations can be implemented in detail, we will have a look at the subject classification systems provided by the large multidisciplinary bibliographic databases and their derivatives. Both, Clarivate Analytics Web of Science Core Collection (WoS) and Elsevier Scopus have their own journal-assignment based subject classifications systems. Scopus provides a 3-level hierarchically structured scheme, while Clarivate provides a fine-grained system of Subject Categories for the WoS and the Journal Citation Reports (JCR) along with a supplementary lower-granularity scheme, e.g., for the Essential Science Indicators (ESI). In 2003, ECOOM Leuven has, jointly with the Budapest group at the Library of the Hungarian Academy of Sciences, developed a hierarchical 4-level subject classification scheme on top of the WoS Subject Categories with three main domains, i.e., the life sciences, natural and applied sciences, the social sciences, the arts and humanities, leading to 15 major subject fields, and 74 subfields built upon the about 250 WoS/JCR Subject Categories (Glänzel et al., 2003). This system has undergone a revision with respect to the social sciences and humanities (Glänzel et al., 2016). We will refer to the revised version here.

Subject granularity is of paramount importance for measuring the cognitive distance between the source subjects integrated in the research under study and thus for disparity aspect in possible IDR indicators. The granularity level has, therefore, to be determined before the assignment of documents to subjects and the identification of disciplines that can be associated with the integrated knowledge sources. In previous studies, we have analysed the effect of the choice of subject granularity on normalised indicators from the three granularity perspectives to gain information on how far indicators on the different granularity levels are correlated, to examine possible changes in their values by changes of the granularity level and to assess the "fuzziness" of the indicator system. In this context we redraw two plotter charts of the study by Glänzel et al. (2009), which gave the plot of subject-normalised citation rates in a 3-year citation window for 676 European universities and research institutions at different hierarchical levels of subject classifications, i.e. the WoS subject categories, the subfields and major fields in the sciences according to the Leuven-Budapest subject classification (see Figure 1). The first straightforward observations concern the strength of the correlation and the slope of the linear regression lines in Figure 1. Its closeness to the value 1.0 is observed, which means that the granularity has practically no "scale-effect" on indicator values. The slightly weaker but still very strong correlation in the second chart on the right-hand side goes with greater variance and a quite large number of outliers reflecting increasing cognitive heterogeneity of subjects when using a lower granularity. Similar results have been found for about 12,000 analysed journals covered by the WoS (cf. Glänzel and Thijs, 2018). This already provides a quantitative argument against the choice of the highest hierarchic levels of subject classification, i.e., larger research areas and major fields.

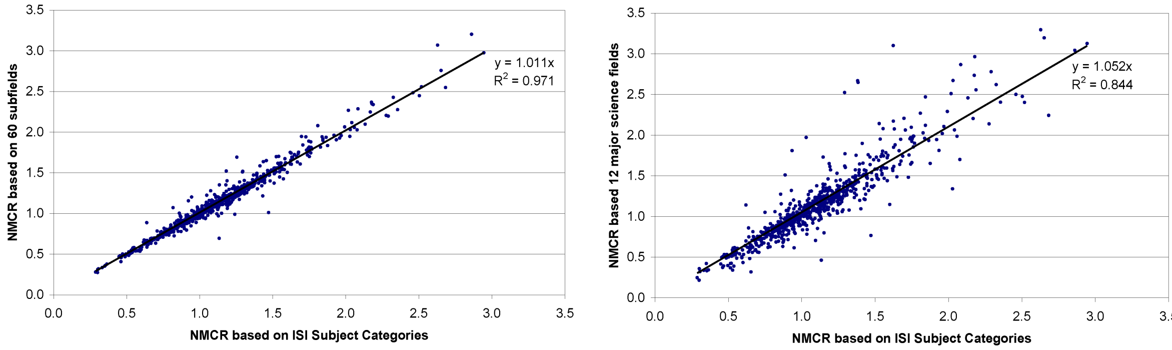

Figure 1. Plot of normalised citation measures based on subfields (left) and major fields (right) versus WoS Subject Categories for 676 European institutions according to Glänzel et al. (2009).

In order to verify these results in the context of subject (dis-)similarity required for IDR studies, we have analysed the similarity matrices based on the 15 major fields, 74 subfields and 252 WoS Categories referred to earlier (Huang et al., 2021; Glänzel et al., 2021) using bibliographic coupling (BC) and cross-citations (CC). Unlike bibliographic coupling and co-citations, which can be interpreted as indirect citation measures, cross-citations are based on direct citation links, where the actual direction (i.e., cited or citing) is mostly ignored. Note that while bibliographic coupling and co-citations can be applied to capture links between individual documents, cross-citation analysis is applied to document sets like journals or subjects, ottherwise it simply reduces to direct document citation, where the direction is ignored. In both cases, we obtained similar standards, where bibliographic coupling reflects a slightly stronger overall similarity. In particular, the mean lies above 0.3 for the major-field level, around 0.2 for subfields and around 0.1 for the WoS Categories. We also checked the minimum similarity (i.e., maximum distance) between one subject and other subjects for the disciplines G (geo & space sciences), H2 (pure mathematics), UT (poetry) and EO (classics), respectively, at the different levels and using BC and CC (cf. Glänzel et al., 2021).

Based on the experience with using BC and CC in network analysis (e.g., Glänzel and Czerwon, 1996; Glänzel and Thijs, 2012), the moderate overall similarity around 0.2 can be considered a quantitative support for choosing the subfield level. This is in line with the conceptual considerations according to which major fields are too coarse with overlaps and lacking overall distance while the lowest level (subject categories) provides a fine-grained but fuzzy subject coverage with frequent, multiple assignments. Subfields could therefore serve as the favoured reference level for disciplines.

Table 1. Subject similarity statistics at three granularity levels based on bibliographic coupling and cross-citations

	BC		**CC**	
	Mean	*Minimum*	*Mean*	*Minimum*
Major Field	0.364	0.248 (G)	0.326	0.180 (G)
Subfields	0.228	0.064 (H2)	0.180	0.038 (K6)
Subject Category	0.139	0.007 (UT)	0.090	0.015 (EO)

Bibliometric groundwork for subject identification and assignment – Individual-document based assignment

In order to measure the knowledge integration of various sources, we have to assign scientific work (in the cognitive approach) to subjects twice, namely, on the one hand, for the reference data and the individual assignment of documents depending on the entities under study since we need to know the subjects involved and their diversity. In particular, we need to create the groundwork for the measurement of variety and disparity that requires the individual subject assignment of articles and their cited references. On the other hand, we also need information on the distance between the underlying subjects to be able to determine the disparity aspect of interdisciplinarity. Even if a moderate or high granularity level is chosen, the applied subject classification schemes are usually based on journal-based subject assignment. Yet, a large number of journals are assigned to "multi-disciplinary" subjects and thus all articles published in these journals too, even if their topic is truly specialised. This would be contradictory to our intention to distinguish between IDR and multi-disciplinarity. This implies that we have to abandon the practice of journal-based subject assignment, at least for papers in multi-disciplinary journals. We have chosen a straightforward approach on the basis of the analysis of the reference literature in individual papers, which can be considered an extension of a method proposed first by Glänzel et al. (1999) and Glänzel and Schubert (2003). The extension implements a weighted multi-generation analysis of cited references as described by Glänzel et al. (2021). This is necessary since the journal information of cited references published in general or multi-disciplinary journals such as Physical Review Letters in physics, JACS or Angewandte Chemie in chemistry or even multidisciplinary journals with no specific subject profile like Science, Nature, PNAS US or PLoS ONE does not reveal useful information on the particular subject of the reference in question. While the above-mentioned approach proposed by Glänzel, Czerwon and Schubert was able to assign about 80% of the papers published in general and multi-disciplinary journals on the basis of their cited references to specific subjects, the weighted two-generation reference analysis can increase the share of individually assignable papers to up to 95% (cf. Glänzel et al., 2021).

The remaining ±5% of articles published in general and multi-disciplinary journals, which could not be assigned individually, proved interdisciplinary, mostly with no dominant discipline in the cited information sources so that the procedure also helps to directly identify interdisciplinary research.

Figure 2 gives two examples of this solution. The largest share of reference literature in Nature refers to biosciences, in particular, to B1 – biochemistry/biophysics/molecular biology, B2 – cell biology and B3 – genetics & developmental biology; while for JASIST, we could identify E1 computer science/information technology and Y1 – education, media & information science as being predominant. The subjects of the remaining articles in both journals are spread over a large number of disciplines with distinctly less weight. The scope of Nature actually reflects the broad subject spectrum of a multi-disciplinary publication venue. By contrast, the overwhelming share of the reference literature in JASIST articles could be assigned to information and computer science.

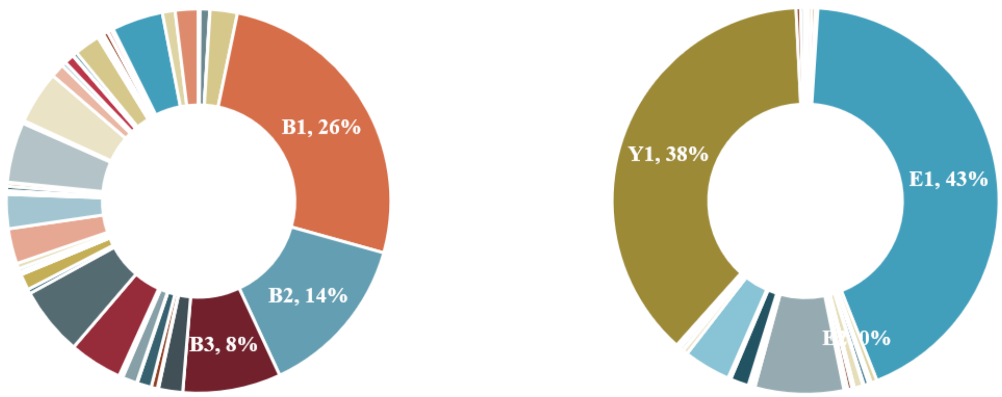

Figure 2. Visualisation of the subject profiles of 'Nature' (left) and 'JASIST (right) based on 74 ECOOM disciplines according to Glänzel et al. (2021)

Once the granularity level has been chosen and a hybrid journal and paper-based subject assignment has been applied to this level, the quantification and measurement of interdisciplinarity can be tackled.

6. Quantification and measurement

The first and foremost issue of quantification refers to the determination of information sources to be used to make integrated knowledge measurable. The most common solution is based on citation links. Within this approach, the analysis of the reference lists of publications proved most efficient (e.g., Porter et al., 2007; Wang et al., 2015; Mugabushaka et al., 2016). An alternative to citation links is exploring IDR on the basis of text mining and lexical approaches. The reason why less research is done on textual analysis probably is, among others, the difficulties in implementing this method globally on the large scale because of lacking vocabulary-based standards as well as the full-text data sources. Some research, however, explored keywords, term analysis and topic model approach in measuring interdisciplinarity (e.g., Ba et al., 2019; Nichols, 2014; Wang et al., 2013; Xu et al., 2016). Dong et al. (2018) offer an integrated method (based on co-occurrence networks and the term interdisciplinarity) for identifying and predicting interdisciplinary topics from scientific literature. At present, most lexical approaches are local solutions (in subject-related terms), but also in this context hybrid citation-lexical solutions are possible to improve efficiency – at least at the local level (see Thijs, 2020).

Quantification is technically implemented through the identification and counting of the frequencies of references, citations and/or text similarity, or other links to knowledge sources and components. Again, two measures are required as has already been mentioned above: variety and disparity. In our approach, we will use two measures, the Hill-type true diversity and the Leinster-Cobbold disparity, based on subject assignment of cited information sources (i.e., the individual articles' reference lists) as discussed, e.g., by Zhang et al. (2016). Unlike in other bibliometric IDR studies, we do not aim at any single all-in-one measure, as there is always at least one relevant aspect that is not reflected by such single measure (cf. Zhang et al., 2016). We just mention in passing that variety and balance do not require any explicit knowledge of distances between subjects, while disparity does. This implies that we may combine variety and balance in one indicator, which will be supplemented by a measure of disparity. For the first one, we proceed from Hill numbers (true diversity), which is defined as

$$^{q}D = \left(\sum_{i=1}^{N} p_i^q\right)^{1/(1-q)} ,$$

where p_i stands for the relative frequency of subject i in references and $q > 0$ is a real parameter. The special choice of $q = 2$, gives the *Inverse Simpson Index*, i.e.,

$$^{2}D = \left(\sum_{i=1}^{N} p_i^2\right)^{-1} .$$

This measure apparently depends on the frequency distribution of cited references by subjects, but does not use any information on their (dis-)similarity.

This measure will be supplemented by Rao's quadratic entropy, which is defined as

$$D_{1,1} = \sum_{i,j=1}^{N} d_{ij} p_i p_j ,$$

where d_{ij} is the dissimilarity of subjects i and j. With this formula, we can readily write the Leinster-Cobbold disparity for q=2 as

$$^2D^S = \left(\sum_{i,j=1}^{N} (1 - d_{ij}) p_i p_j \right)^{-1} = \frac{1}{1 - D_{1,1}}$$

The latter indicator measures the dissimilarity of the information sources referred to weighed with the frequency of their occurrence in the reference list. $^2D^S$ will, therefore, serve as the disparity measure of our choice and accompany the above variety index ^2D.

Different methods such as granularity, subject assignment, and similarity measures (e.g., bibliographic coupling, co-citation, lexical), of course, result in different standards. This applies to frequency-based counting and the calculation of the underlying distance matrix of disciplines depending on those methods. In order to obtain commensurable results, proper, preferably self-adjusting normalisation is required. We decided to use the method of *Characteristic Scores and Scales* (CSS) for this purpose. As in other bibliometric applications too, CSS only depends on the parameter of the power-law approximation of the underlying Waring distribution (cf. Glänzel, 2007). In particular, for the two IDR measures ^2D and $^2D^S$, we define the following four classes. Class 1 (CSS1) stands for low, Class 2 (CSS2) for fair, Class 3 (CSS3) for remarkable and Class 4 (CSS4) for outstanding standard of variety and disparity, respectively. Classes 3 and 4 can be combined and used to identify high standard, notably if samples are rather small. CSS proved robust regarding time, periods and disciplines, and the classes follow a distribution of roughly CSS1 ≈ 70%, CSS2 ≈ 21%, CSS3 ≈ 6.5% and CSS4 ≈ 2.5%, although classes are not directly linked to percentiles (cf. Glänzel, 2007; Glänzel et al., 2019).

7. Further perspectives: Interdisciplinarity and citation impact

One interesting aspect of interdisciplinarity still remains to be studied: Does a larger extent of interdisciplinarity also exhibit a higher citation impact? This question suggests itself since increasing interdisciplinarity, notably if this goes together with a more intense collaboration and a larger extent of disparity, would mean the integration of a broader knowledge base, which, in turn, would open research to a potentially larger community and user group of published information. A limited number of studies suggested that IDR results in different forms of impact (cf. Molas-Gallart et al., 2014). The results are, however, not unambiguous (Abramo et al, 2017; Wang et al., 2015) and the applied methods are also under dispute (Adams et al, 2016).

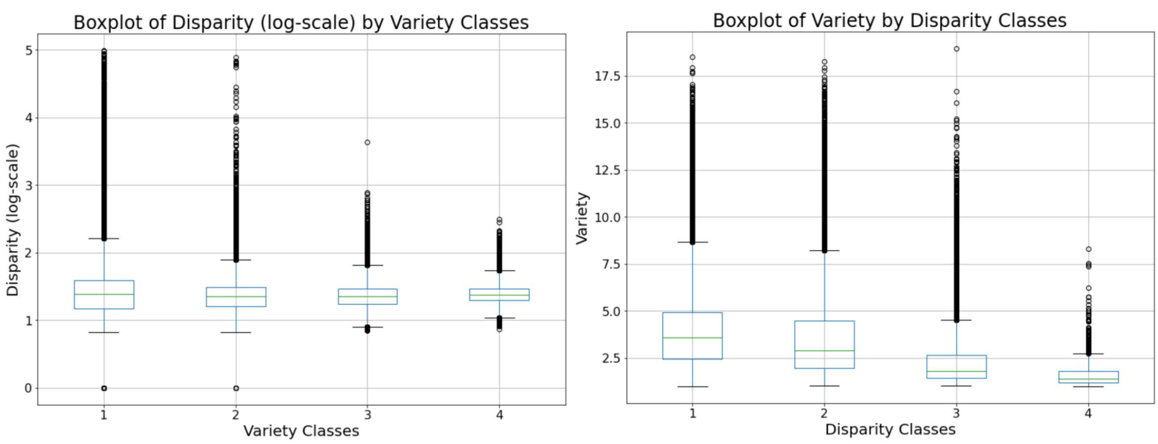

Figure 3. Boxplot of variety by disparity CSS classes

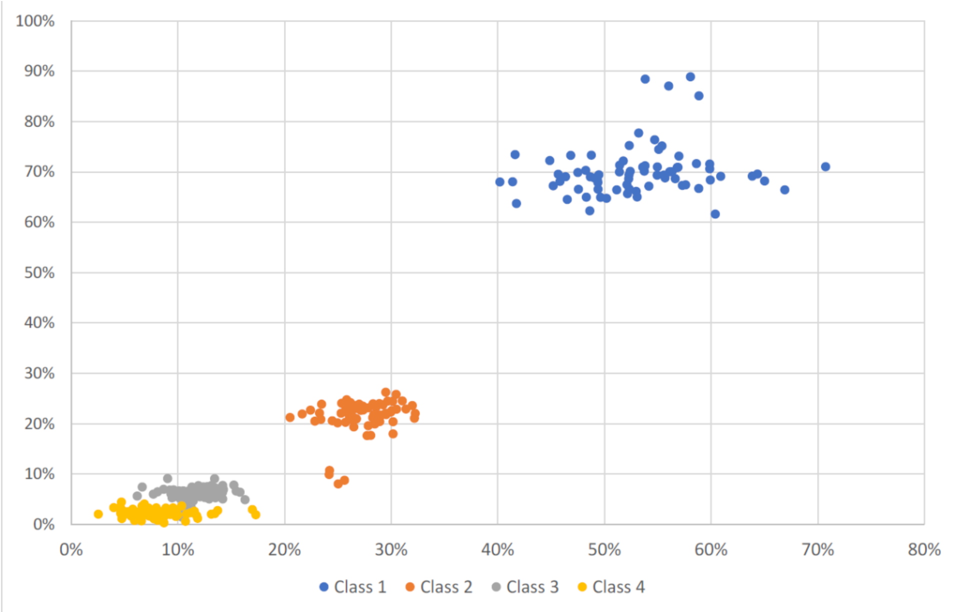

Figure 4. Scatter plot of disparity vs citation impact in each citation class

In particular, Molas-Gallart et al. have stressed in their study that increasing impact and increasing interdisciplinarity are not systematically positively correlated, which was already stressed by Larivière and Gingras (2010). Yegros-Yegros et al. (2015) mentioned in this context that the aspect of opening up perspectives is not directly reflected by high numbers of citations. The question of whether scientific literature showing a higher degree of knowledge integration is more cited as well, is rather complex, even if all measures are systematically normalised since communication behaviour in the various fields that are involved, may have different standards.

If we wish to apply an indicator set to measure the two basic dimensions of interdisciplinarity and citation impact of research, we must guarantee the components of this set are largely uncorrelated, which is not self-evident since the three measures are based on citation links that may be even strongly interrelated. The following example, however, shows that the choice of indicators satisfies the requirement of low correlation.
First, the necessity of using two measures of interdisciplinarity is demonstrated by the box plots of disparity and variety CSS classes in Figure 3, the rank correlation of which (–0.11 with p-value=0.000) reflects a weak negative correlation, practically almost uncorrelatedness. Figure 4 reveals that the chosen interdisciplinarity measures and citation impact are similarly weakly correlated. In particular, the two indicators, disparity and citation impact, are weakly correlated in each citation class as determined by applying the Characteristic Scores and Scales method (Glänzel et al, 2019).
Concluding from the above observations, we can state that the variety-disparity-citation impact indicator-triplet has the potential to provide a publications set's unique interdisciplinarity profile.

8. Limitations, caveats and pitfalls

Bookstein (1997) noted three (out of other) demons to measurement that are challenges to quantitative approaches. In particular, he mentioned *randomness*, *fuzziness* and *ambiguity*. This applies to both concepts and methodology, and to the measurement and indicator design. While we may be able to cope with the randomness, fuzziness and ambiguity remain crucial in the context of IDR studies. Fuzziness results, for instance, from multiple assignments with possible redundancies and from subjects of interdisciplinary nature. Ambiguity is even more complex as different approaches with unclearly structured fields and lacking concordance between these approaches (e.g., based on affiliations, skills, literature sources) may lead to inconsistent results. According to Adams et al. (2016), for instance, the same project may be indexed as interdisciplinarity for one parameter (e.g., departmental affiliations) and not for another (the cognitive aspect based on literature references). Zhang et al. (2018) examined two different aspects of interdisciplinarity: the disciplines associated with authors' affiliations and the subject categories of cited documents in their reference lists. Each approach, each concept, aspect can reflect such a multi-faceted phenomenon as IDR only in an incomplete manner. According to the above-mentioned study by Adams et al., the choice of data, the methodology, and the indicators can produce seriously inconsistent and even contradictory outcomes. Leydesdorff and Rafols (2011), however, stressed that contradiction between two indicators does not mean either of them is invalid.

Insufficient information, inadequate assignment and ill-balanced reflection of knowledge sources in the researchers' contribution and the subjects of cited literature may result in unintended misinterpretation. Observed distortions may, among others, be the result of unresolvable inconsistencies, multi-disciplinary assignment, mandatorily cited standard work, technical support but otherwise cognitively less relevant contribution.

And finally, scientific research is a global endeavor. The example of Italy (cf. Abramov et al., 2012, 2017) shows that well-elaborated and validated national and regional approaches can only be of local significance as long as they cannot be embedded into a consistent global system with complete integration of all external collaborators and boundary-crossing cognitive links for complete measurement and benchmarking.

Notwithstanding those critical reflections and considerations, the indicators developed and validated in this paper show that robust approaches can be devised to unravel and to measure interdisciplinarity from a bibliometric perspective, on condition the right level of granularity is applied to the bibliometric data.

Declaration of Competing Interests

The first author (Wolfgang Glänzel) is the editor-in-chief of Scientometrics, Koenraad Debackere is member of the Distinguished Reviewers Board of Scientometrics.

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Figure 1 has been reproduced from Glänzel et al. (2009) with permission of the publisher. Figure 2 is a part of Figure 6 in Glänzel et al. (2021) with permission of the authors.

References

Abramo, G., D'Angelo, C.A., Costa, F.D. (2012). Identifying interdisciplinarity through the disciplinary classification of coauthors of scientific publications. *JASIST*, 63(11), 2206–2222.

Abramo, G., D'Angelo, C.A., Di Costa, F. (2017). Do interdisciplinary research teams deliver higher gains to science? *Scientometrics*, 111(1), 317–336.

Adams, J., Loach, T., Szomszor, M. (2016). *Interdisciplinary Research: Methodologies for Identification and Assessment*. Digital Research Reports. London (UK): Digital Science.

Allmendinger, J. (2015). *Quests for interdisciplinarity: a challenge for the ERA and HORIZON 2020*. Brussels: European Commission.

Ba, Z., Cao, Y., Mao, J., et al. (2019). A hierarchical approach to analyzing knowledge integration between two fields – A case study on medical informatics and computer science. *Scientometrics*, 119(3), 1455–1486.

Bookstein, A. (1997), Informetric distributions. III. Ambiguity and randomness. *JASIS*, 48(1), 2–10.

Choi, B.C., Pak, A.W. (2006). Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. *Clinical and Investigative Medicine, 29*(6), 351–364.

COSEPUP (2004). *Facilitating interdisciplinary research*. Paper presented at the National academies committee on facilitating interdisciplinary research, committee on science, engineering and public policy (COSEPUP) 2004, Washington, DC, 306 p. Accessible at https://www.nap.edu/download/11153.

Dong, K., Xu, H., Luo, R., Wei, L., Fang, S. (2018). An integrated method for interdisciplinary topic identification and prediction: A case study on information science and library science. *Scientometrics*, 115(2), 849–868.

Dou, H. (2017). *A catalyst for interdisciplinarity in Science: the patent information*. Competitive Intelligence Worldwide's Interdisciplinary Symposium, Corte, Corsica, July 5–7. Accessible at https://s244543015.onlinehome.fr/ciworldwide/wp-content/uploads/2017/08/informationscience_dou.pdf

Fanelli, D., Glänzel, W. (2013), Bibliometric evidence for a Hierarchy of the Sciences. *PLoS ONE*, 8(6), Article Number: e66938.

Flinterman, J.F., Teclemariam-Mesbah, R, Broerse J.E.W., Buders, J.F.G. (2001), Transdisciplinary: the new challenge for biomedical research. *Bulletin of Science, Technology & Society*, 21(4), 253–266.

Glänzel, W., Czerwon, H.J. (1996), A new methodological approach to bibliographic coupling and its application to the national, regional and institutional level. *Scientometrics*, 37(2), 195–221.

Glänzel, W., Schubert, A., Czerwon, H.J. (1999), An item-by-item subject classification of papers published in multidisciplinary and general journals using reference analysis. *Scientometrics*, 44(3), 427–439.

Glänzel, W., Schubert, A. (2003), A new classification scheme of science fields and subfields designed for scientometric evaluation purposes. *Scientometrics*, 56(3), 357–367.

Glänzel, W. (2007), Characteristic scores and scales. A bibliometric analysis of subject characteristics based on long-term citation observation. *Journal of Informetrics*, 1(1), 92–102.

Glänzel, W., Schubert, A., Thijs, B., Debackere, K. (2009). Subfield-specific normalized relative indicators and a new generation of relational charts: Methodological foundations illustrated on the assessment of institutional research performance. *Scientometrics*, 78(1), 165–188.

Glänzel, W., Thijs, B. (2012), Using 'core documents' for detecting and labelling new emerging topics. *Scientometrics*, 91(2), 399–416.

Glänzel, W., Beck, R., Milzow, K., Slipersæter, S., Tóth, G., Kolodziejski, M., Chi, P.S. (2016), Data collection and use in research funding and performing organisations. General outlines and first results of a project launched by Science Europe. *Scientometrics*, 106(2), 825–835.

Glänzel, W., Thijs, B. (2018), The role of baseline granularity for benchmarking citation impact. The case of CSS profiles. *Scientometrics*, 116(1), 521–536.

Glänzel, W., Thijs, B., Huang, Y. (2021), *Improving the precision of subject assignment for disparity measurement in studies of interdisciplinary research*. Proceedings of the 18th International Conference of the International Society of Scientometrics and Informetrics, Leuven University Press, 453–464.

Glänzel, W., Thijs, B., Debackere, K. (2019), *Citation classes: A distribution-based approach to profiling citation impact for evaluative purposes*. In: W. Glänzel, H. Moed, U. Schmoch, M. Thelwall (Eds.), Springer Handbook of Science and Technology Indicators. Springer International Publishing – Berlin, Heidelberg, 335–360.

Huang, Y., Thijs, B., Glänzel, W. (2021), *A framework for measuring the knowledge diffusion impact of interdisciplinary research*. Proceedings of the 18th International Conference of the International Society of Scientometrics and Informetrics, Leuven University Press, 533–538.

Huutoniemi, K., Klein, J.T., Bruun, H., Hukkinena, J. (2010). Analyzing interdisciplinarity: Typology and indicators. *Research Policy*, 39(1), 79–88.

Klein, J.T. (1990). *Interdisciplinarity: History, Theory, and Practice*. Detroit, MI: Wayne State University Press.

Ko, N., Yoon, J., Seo, W., (2018), Analyzing interdisciplinarity of technology fusion using knowledge flows of patents. *Expert systems with applications*, 41(42), 1955–1963.

Lan, G., Katrenko, S., Pan, L., (2015). *Analyzing Interdisciplinary Research along multiple dimensions of research impact*. ASIS&T METRICS Workshop, St Louis, September 24, 2015. Accessible at https://www.asist.org/SIG/SIGMET/wp-content/uploads/2015/10/sigmet2015_paper_14.pdf

Larivière, V., Gingras, Y. (2010). On the relationship between interdisciplinarity and scientific impact. *JASIST*, 61(1), 126–131.

Leahey, E., Beckman, C.M., Stanko, T.L. (2017) Prominent but less productive, The impact of interdisciplinarity on scientists' research. *Administrative Science Quarterly*, 62(1), 105–139.

Ledford, H., (2015). How to solve the world's biggest problems. *Nature*, 525, 208–211.

Leydesdorff, L., Rafols, I. (2011). Indicators of the interdisciplinarity of journals: Diversity, centrality, and citations. *Journal of Informetrics*, 5(1), 87–100.

Magerman, T., Van Looy, B., Debackere, K. (2015), Does involvement in patenting jeopardize one's academic footprint? An analysis of patent-publication pairs in biotechnology. *Research Policy*, 44: 1702-1713.

Mazzocchi, F. (2019), Scientific research across and beyond disciplines. *EMBO Reports*, 20: e47682.

Mugabushaka, A.M., Kyriakou, A., Papazoglou, T. (2016), Bibliometric indicators of interdisciplinarity: the potential of the Leinster-Cobbold diversity indices to study disciplinary diversity. *Scientometrics*, 107(2), 593–607.

Molas-Gallart, J., Rafols, I., Tang, P. (2014), On the relationship between interdisciplinarity and impact: different modalities of interdisciplinarity lead to different types of impact. *Journal of Science Policy and Research Management*, 29(2), 69–89, NSF (2013), *Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE)*. Accessible at: https://www.nsf.gov/pubs/2013/nsf13518/nsf13518.htm

Nichols, L.G. (2014). A topic model approach to measuring interdisciplinarity at the National Science Foundation. *Scientometrics*, 100(3), 741–754.

Porter, A.L., Roessner, J.D., Cohen, A.S., Perreault, M. (2006). Interdisciplinary research: Meaning, metrics and nurture. *Research Evaluation*, 15(3), 187–195.

Porter, A.L., Cohen, A.S., Roessner, J.D., Perreault, M. (2007), Measuring researcher interdisciplinarity, *Scientometrics*, 72(1), 117–147.

Rafols, I. (2014), *Knowledge integration and diffusion: Measures and mapping of diversity and coherence*. In: Ding Y., Rousseau R., Wolfram D. (eds), Measuring scholarly impact Springer, Cham. pp. 169–190.

Rafols, I., Meyer, M. (2010). Diversity and network coherence as indicators of interdisciplinarity: Case studies in bio-nanoscience. *Scientometrics*, 82(2), 263–287.

Rousseau, R., Guns, R., Rahman, A.I.M.J., Engels, T.C.E. (2017). Measuring cognitive distance between publication portfolios. *Journal of Informetrics*, 11(2), 583–594.

Stirling, A. (1994). Diversity and ignorance in electricity supply investment: Addressing the solution rather than the problem. *Energy Policy, 22*(3), 195-216.

Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface, 4*(15), 707-719.

Stokols, D., Fuqua, J., Gress, J., et al. (2003). Evaluating transdisciplinary science. *Nicotine & Tobacco Research*, 5(Suppl. 1), S21–S39.

Strauss, B.S. (2019). A physicist's quest in biology: Max Delbrück and complementarity. *Genetics*, 206(2): 641-650.

The Royal Society (2016), *Response to the British Academy's call for evidence on 'Interdisciplinarity'*, Accessible at: https://royalsociety.org/~/media/ policy/Publications/2015/29-06-15-rs-response-to- ba-inquiry-interdisciplinarity.pdf.

Thijs, B. (2020), *On the added value of networked data and graph embeddings over convolutional neural networks for the classification of scientific publications*. Paper presented at the GTM 2020 Virtual Conference, 12 November 2020.

Wang, L., Notten, A., Surpatean, A. (2013). Interdisciplinarity of nano research fields: a keyword mining approach. *Scientometrics*, 94(3), 877-892.

Wang, J., Shapira, P. (2015). Is there a relationship between research sponsorship and publication impact? An analysis of funding acknowledgments in nanotechnology papers. *PloS ONE*, 10(2), e0117727.

Wang, J., Thijs, B., Glänzel, W. (2015). Interdisciplinarity and Impact: Distinct Effects of Variety, Balance and Disparity. *Plos One*, 10(5): e0127298.

Wickson, F., Carew, A. L., Russell, A.W. (2006). Transdisciplinary research: characteristics, quandaries and quality. *Futures*, 38(9), 1046–1059.

Xu, H., Guo, T., Yue, Z., Ru, L.J., Fang, S. (2016). Interdisciplinary topics of information science: a study based on the terms interdisciplinarity index series. *Scientometrics*, 106(2), 583–601.

Yegros-Yegros, A., Rafols, I., D'Este, P. (2015). Does interdisciplinary research lead to higher citation impact? The different effect of proximal and distal interdisciplinarity. *PLoS ONE*, 10(8), e0135095.

Zhang, L., Rousseau, R., & Glänzel, W. (2016), Diversity of references as an indicator for interdisciplinarity of journals: Taking similarity between subject fields into account. *JASIS*, 67(5), 1257–1265.

Zhang, L., Sun, B., Chinchilla-Rodrígue, Z., Chen, L., Huang, Y. (2018), Interdisciplinarity and collaboration: On the relationship between disciplinary diversity in departmental affiliations and reference lists. *Scientometrics*, 117(1), 271–291.