Application of an "interdisciplinarity" metric at the paper level and its use in a comparative analysis of the most publishing ERA and non-ERA universities

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Abstract

This paper presents the application—in a large bibliographic database—of an "interdisciplinarity" metric measuring the extent to which knowledge from a priori disconnected subfields is integrated within individual scientific papers. This metric is then used to study interdisciplinarity patterns over time and across subfields, as well as to perform a comparative analysis of the interdisciplinarity of ERA (European Research Area) and non-ERA universities. Excluding the social sciences and humanities, the results show that interdisciplinarity is increasing over time and that it is generally more pronounced in applied research fields. In fact, technical universities are over-represented among universities having a greater proportion of highly "interdisciplinary" papers. This suggests that research drawing on a broad range of knowledge can potentially spur the emergence of novel technologies, as applied research is closer to innovation than the more fundamental research performed in the natural or health sciences. Although ERA universities did not score as highly for interdisciplinarity as non-ERA universities generally, technical universities within the ERA were highly over-represented among universities having a greater proportion of highly interdisciplinary papers. The lower score of ERA universities in aggregate is therefore attributable to the non-technical universities. It is somewhat intriguing why such a dichotomy is not observed outside the ERA between technical and non-technical universities. Note that the strong limitations of this indicator, as they are depicted in this paper, call for more research on interdisciplinarity metrics.

Keywords

interdisciplinarity; universities; innovation; research excellence; science policy

Introduction

Empirical research results have shown, at least in certain fields of science and technology, a slow upward trend towards research that crosses disciplinary boundaries (Porter & Rafols, 2009). It has been suggested by several academics that this type of research can have positive effects on the production of scientific knowledge (Gibbons et al., 1994). As a result, this mode of research has attracted much attention from governments, which are increasingly fostering such endeavours through various funding programmes (Van Rijnsoever & Hessels, 2011), such as the Seventh Framework Programme for Research (FP7) in Europe.

Various subdimensions of this mode of research are reported in the literature, including—in ascending order of the level of knowledge integration—multidisciplinary, interdisciplinary, and transdisciplinary collaboration (Sonnenwald, 2007; Wagner et al., 2011). Multidisciplinary collaboration typically involves researchers from more than one discipline without a true integration of knowledge; for example, an author might borrow some equipment from a co-author without exchanging any knowledge or ideas with him or her. Interdisciplinary collaboration also involves more than one discipline, but this time the knowledge of the various disciplines is integrated to address a problem that is generally beyond the scope of any one discipline. Transdisciplinary collaboration brings together all disciplines and knowledge relevant to a real-world problem. It frequently involves not only several disciplines but multiple non-academic participants as well. It is considered to be the most integrative approach.

As evidenced through discussions held between European Commission officials and various experts from all sectors of activity on the occasion of the "Use of indicators for STI Policy Workshop",[1] a clear emphasis is being placed on interdisciplinary research within the context of Horizon 2020, the successor programme to FP7. Indeed, this mode of research is expected to spur innovation, thereby strengthening the competitiveness of the European Research Area (ERA). As a result, there is an urgent need for data in order to enable the monitoring of progress towards greater interdisciplinary research, as well as to document the effects of such changes on the research and innovation system.

This paper responds to the current needs of the research policy community by presenting the application—to a large bibliographic database—of a metric measuring the integration of knowledge from various disciplines within individual scientific papers. This metric can subsequently be used in producing aggregated statistics at any level of analysis. Since the metric is not based on the disciplinary mix observed among the co-authors of a paper, but rather on the disciplinary mix observed within the cited references of a paper, it is assumed that it truly reflects the extent to which the reported work integrated knowledge from different disciplines, as opposed to reflecting the mere interaction of researchers from different disciplines without integration of knowledge.

On the other hand, this metric does not entail that the observed integration of knowledge from various disciplines comes from the collaborative work of researchers in different disciplines or any other type of collaborative work. For instance, a researcher alone could rely on, and integrate, knowledge from many disciplines in solving a problem. However, it is assumed that in most disciplines this latter possibility is less likely to lead to a high diversity of subfields among the cited references of a paper than interdisciplinary collaboration. As such, the proposed metric is used as a proxy of interdisciplinarity.

This paper first presents a comprehensive method addressing all the challenges that were faced in applying this metric. It subsequently presents its use in studying interdisciplinarity patterns over time and across subfields, as well as in performing a comparative analysis of the interdisciplinarity of ERA and non-ERA universities. The paper ends with a discussion of the findings and limitations of the proposed metric.

[1] The workshop was held in Brussels (Belgium) at the Commission premises of DG RTD on 21 January 2015.

Methods

Data sources

To produce an unbiased interdisciplinarity metric using the cited references of scientific papers, it is necessary to obtain a database that indexes both peer-reviewed papers and all of the papers they are referencing. This is to obtain a comprehensive account of all the knowledge the reported research was built upon. Unfortunately, there is no single database that indexes all of the peer-reviewed literature in the world.

Elsevier's Scopus database and Thomson Reuters' Web of Science (WoS) are currently the best choices in this regard. Since the former database offers a more comprehensive coverage of the scientific literature published worldwide, it might provide a better account of the full range of knowledge upon which the research disclosed in a given paper relied. However, its more limited time coverage (1996−2014) compared to the WoS (early 1980s up to 2014) might partly offset this advantage. Indeed, only a limited share of the references of papers published in the late 1990s are indexed in Scopus relative to the WoS. Thus, coverage issues that could lead to important biases in measuring the interdisciplinarity of papers using the proposed metric are observed in both databases. The whole of Scopus was finally retained for this study (i.e., 1996–2014). The documents in Scopus were filtered to retain peer-reviewed papers only (mostly research articles and conference papers), though reviews were excluded since they behave very differently in terms of the number of references they include and often do not report new research that could result from interdisciplinary work.

The paper-level interdisciplinarity metric

The integration metric of Porter & Rafols (2009) was applied to quantify the diversity (i.e., variety, balance and distance) of disciplines integrated in a single paper, for all papers in Scopus. Please refer to their papers for technical details on the computation of the metric. Briefly, it consists of measuring the diversity of disciplines in which the cited references of a single paper are classified relative to a reference set of papers, while taking into account the similarities between scientific disciplines based on the propensity with which they are exchanging knowledge (Rafols and Meyer, 2010). The disciplines used in computing this metric consist of the subfields in Science-Metrix's three-level classification tree of scientific journals (i.e., 6 domains, 22 fields and 176 subfields) (Archambault, Caruso & Beauchesne, 2011). Note that this classification is mutually exclusive, meaning that journals cannot be classified into more than one subfield.

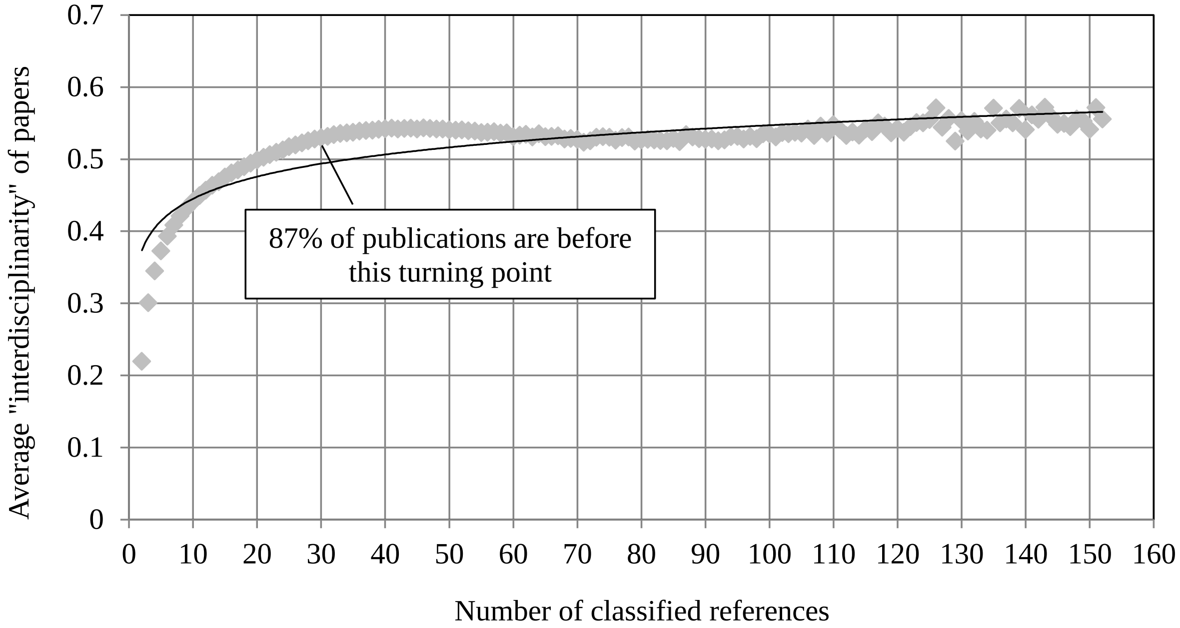
The interdisciplinarity of each paper within the database is measured by comparing the frequency distribution of subfields within its references to a proximity matrix between scientific subfields. This matrix provides the pairwise similarity of subfields based on their co-occurrence patterns within the references of individual scientific papers in the database as a whole. Using this matrix in computing the interdisciplinarity indicator gives more weight to unusual co-citation patterns relative to those that are very common. The interdisciplinarity of a given paper can take values in the range from 0 (i.e., monodisciplinary) to 1 (i.e., highly interdisciplinary).

Subsequently, the interdisciplinarity of an entity (i.e., a researcher, an organisation, a region or a country) can be obtained by averaging the scores of its papers or by computing the proportion of its papers falling within the 10% most interdisciplinary papers in the database.

Coverage issues

Before producing aggregated statistics using this metric, one must first document the potential biases that could result from the aforementioned coverage issues. To do so, a test was first conducted to see whether there is a correlation between the number of classified references of papers and their interdisciplinarity. For instance, in the presence of a positive correlation, coverage issues could lead to important biases in inter-field or inter-annual comparisons. Although the correlation coefficient between these variables is rather moderate (0.37), a logarithmic relationship is detected when regressing the average interdisciplinarity of papers with their number of classified references (R^2 = 0.72, Figure 1).

Figure 1. Relationship between the average interdisciplinarity of papers and their number of classified references (1996−2014)



In fact, the bulk of papers in the database (87%) have fewer than or at most 30 classified references and therefore fall in the portion of the relationship where the number of classified references available to compute the interdisciplinarity of papers has the largest influence on the resulting scores. Given the coverage issues discussed above, this relationship could lead to strong biases if it is not appropriately dealt with. Indeed, the variation in the number of classified references across papers is far from reflecting the "natural" variation that could be attributable to the breadth of knowledge upon which the authors of the respective papers have built their research; it is most likely that only a fraction of a paper's total references are indexed and classified in Scopus, and that these indexed references are not uniformly distributed across years and scientific subfields. Figure 2 shows how rapidly the average share of total references that are indexed and classified in Scopus is increasing over time, while Table 1 shows the strong variability that exists in this share across scientific subfields.

Figure 2. Average share of total references that are indexed and classified in Scopus is increasing over time, 1996−2014

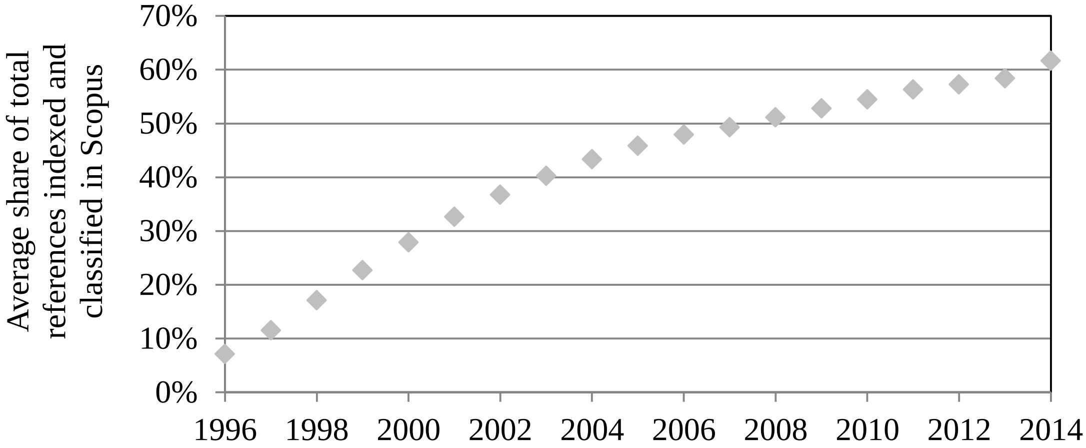


Table 1. Average share of total references that are indexed and classified in Scopus across selected subfields (1996−2014)

Subfield	**Avg. no. of indexed/classified references**	**Avg. no. of total references**	**Average share**
History	2.89	94.77	4.7%
Classics	2.05	63.60	5.1%
…	…	…	…
Building & Construction	8.94	24.48	35.0%
Civil Engineering	6.90	18.98	35.5%
…	…	…	…
Nanoscience & Nanotechnology	21.00	29.17	67.8%
Developmental Biology	31.28	45.64	68.3%

To cope with these coverage issues, a first attempt was made to normalise the interdisciplinarity score of any given paper by the average score of papers sharing the same number of classified references and to standardise the normalised values between 0 and 1. Note that using this approach, papers with only one classified reference are left aside since their interdisciplinarity score is always equal to zero and can therefore not be normalised to correct the bias related to the share of a paper's references that are indexed and classified.

Unfortunately, this approach leads to an over-normalisation of papers with very few references since most of these papers had a score of 0 prior to normalisation, implying that all other papers were well above the mean used in normalising the score. The result was that a majority of papers had a score of 0 once normalised, with the remaining papers having very high scores and with none of them falling in the lower range of possible values (i.e., 0.1 to 0.5; see Figure 3a for 2 references). For all papers with at least 25 references, the distribution became smoother and mostly symmetrical around a normalised score of 0.5 (Figure 3b shows the result for 25 references).

Figure 3. Frequency distribution of papers with 2 (a) or 25 (b) classified references based on their normalised interdisciplinarity scores (1996−2014)

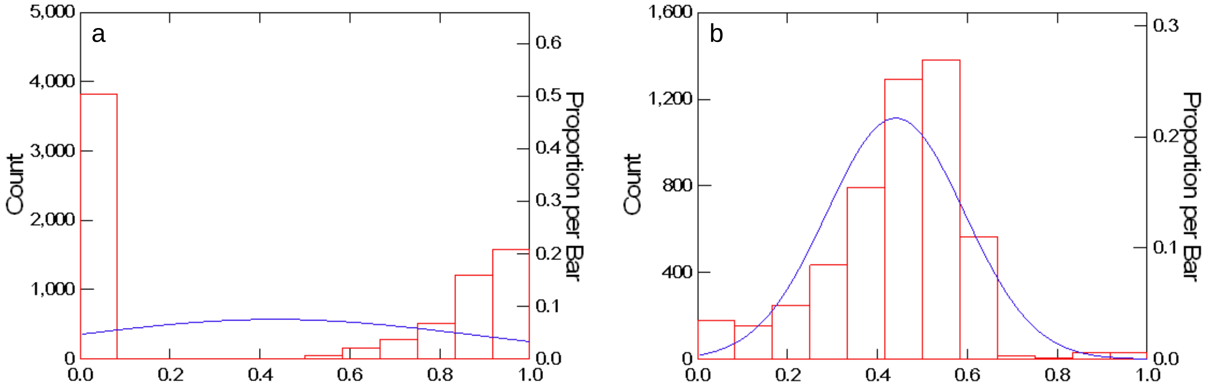
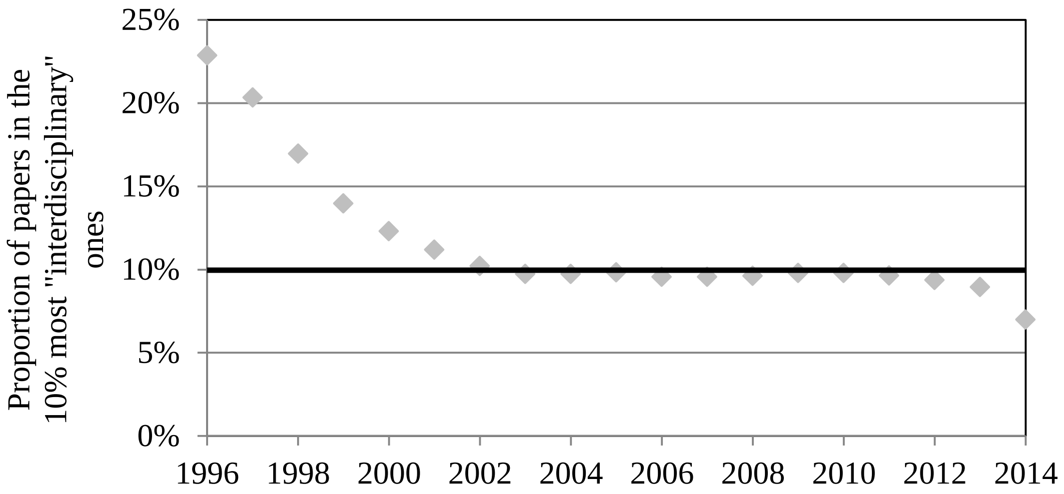


Figure 4 shows that this approach clearly overestimates the scores of years for which the scores were originally underestimated. Indeed, one can see that the proportion of papers in the 10% most interdisciplinary ones—when using the standardised scores—is very high in the late 1990s. It subsequently drops to expectation (i.e., 10%) in 2002, after which it remains roughly stable up to 2013 when it starts declining further. When looking at Figure 2, these results suggest that when 30% or fewer of the references of a paper are indexed and classified, this approach can lead to an overestimation of the scores, which could be the case for many subfields (e.g., in the arts and humanities) in which the scores were originally underestimated due to the database limitation.

Figure 4. Overall trend in the proportion of papers within the 10% most interdisciplinary ones based on the standardised scores, 2000−2014



Another approach was instead applied that consisted in the use of a minimum threshold in terms of the number of classified references below which the papers are not considered. This was achieved by looking exclusively at the 1% of papers having the largest number of references in each subfield. The 1% threshold was set so as to ensure that the minimum number of classified references in any of the retained papers was 10, with very few papers below the turning point beyond which the increase in the number of references does not much influence the resulting score of papers (i.e., about 30 references, see Figure 1). Using this approach, about 2,700 of the retained papers (212,617) have fewer than 30 classified references and all subfields are represented proportionately to their overall presence in Scopus. Using these papers only, the correlation between the number of references of papers and their interdisciplinarity score fell to 0.02— a nearly sixteen-fold decrease relative to the approach without correction.

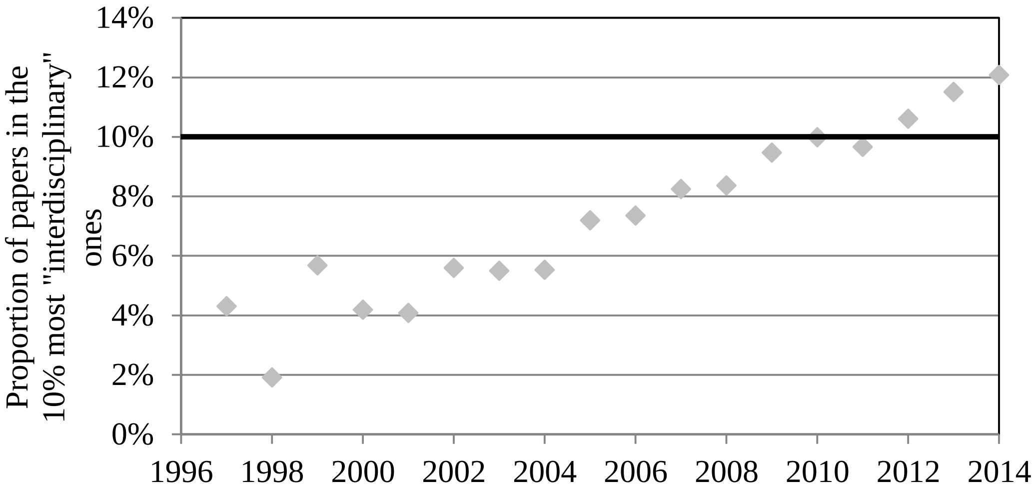
A downside of this approach is that the “variety” aspect of diversity (i.e., number of distinct disciplines in the references of a paper) is given less weight than the “balance” and “distance” aspects, since papers with few references are omitted. On the other hand, focusing on the highly interdisciplinary papers appeared to us as a reasonable choice when manually examining the content of papers in relation to their interdisciplinarity scores. This inspection revealed that it was easiest to interpret data when focusing on papers with high interdisciplinarity scores of at least 0.7 because these are papers that undoubtedly recombined knowledge from a diversified set of somewhat disconnected disciplines. This is also why using the proportion of the retained papers that fall in the 10% of papers with the highest interdisciplinarity score (i.e., scores of at least 0.70) is preferred over the average of the scores in computing the aggregated scores of entities. The average provides scores in a limited range of values for which the meaning of the scores are not documented well enough to interpret the magnitude of observed differences (i.e., we do not yet know if a difference of 0.05 for scores around 0.5 is meaningful).

Results

Yearly trend and pattern across subfields

When aggregating the data by year, one can see that interdisciplinarity is increasing over time and that only recently have more papers been observed among the 10% most interdisciplinary (Figure 5). This method did not lead to an overestimation of the scores in the late 1990s and early 2000s, for which a very small share of references are indexed and classified. Still, note that in the remaining analyses, only the years beyond 2001 are considered in order to eliminate the most problematic years.

Figure 5. Overall trend in the proportion of papers within the 10% most interdisciplinary ones among the 1% of papers having the largest number of references in each subfield, 1996−2014



When aggregating the values at the highest level of the classification tree of journals, three domains score above expectations (i.e., have more than 10% of their papers in the 10% most interdisciplinary ones) for the 2002–2013 period. These are the arts & humanities (18.2%; 19.7% using standardised scores), the economic & social sciences (15%; 12.6% std. scores) and the applied sciences (13.2%; 14.4% std. scores). The remaining three domains fall below expectations—namely, the general sciences (8.7%; 9.4% std. scores), natural sciences (8.2%; 7% std. scores) and the health sciences (7.5%; 5.4% std. scores). These findings appear robust to changes in the correction method (i.e., normalisation and standardisation or filtering the top 1% of papers with the largest number of classified references) in spite of their respective limitations.

ERA versus non-ERA universities

To compare trends in Europe to the rest of the world, the 100 universities with the largest number of publications in Scopus in the 2007−2013 period in ERA Associated Countries were selected, as well as the 100 most publishing universities outside these countries. The main findings are as follows:

- Technical universities are clearly over-represented among organisations with scores above the median of the proportion of papers falling in the 10% most interdisciplinary ones (Table 2).
- While there is a similar share of technical universities among the selected ERA (16%) and non-ERA universities (15%), ERA universities are clearly under-represented among organisations above the median, whereas non-ERA universities are clearly over-represented (Table 3).
- The under-representation of ERA universities above the median is attributable to their non-technical universities. In fact, technical universities within the ERA exhibit the highest representation above the median. Among non-ERA universities, the opposite is observed, with technical universities being slightly under-represented above the median (Table 4). However, this latter finding is the only one that does not hold when changing the correction method (i.e., when using the standardised scores instead of the top 1% filter, data not shown). It is therefore concluded that among non-ERA universities, technical and non-technical universities do not behave so much differently relative to one another.

Table 2. Comparing the proportion of technical and other universities with scores below/above the median of the proportion of papers falling in the 10% most interdisciplinary ones using the top 1% filter (2007–2013)

Category	Share of universities below median	Share of universities above median
Technical universities	37%	63%
Other universities	52%	48%

Table 3. Comparing the proportion of ERA and non-ERA universities with scores below/above the median of the proportion of papers falling in the 10% most interdisciplinary ones using the top 1% filter (2007–2013)

Category	Share of universities below median	Share of universities above median
ERA universities	65%	35%
Non-ERA universities	35%	65%

Table 4. Comparing the proportion of ERA/non-ERA as well as technical/other universities with scores below/above the median of the proportion of papers falling in the 10% most interdisciplinary ones using the top 1% filter (2007–2013)

	ERA		Non-ERA	
Category	Share of universities below median	Share of universities above median	Share of universities below median	Share of universities above median
Technical universities	21%	79%	54%	46%
Other universities	72%	28%	32%	68%

Discussion

In the social sciences and humanities (SSH), where co-authored papers are less frequent, the proportion of highly interdisciplinary papers above expectation might indicate that the problems being tackled are often of relevance to an appreciable diversity of a priori disconnected subjects, rather than to interdisciplinary collaboration per se (i.e., with multiple authors). For instance, in drama and theatre, there are examples of single authored papers or papers resulting from monodisciplinary collaboration that build on a diversified knowledge base to study dance education among disabled persons. These papers often recombine knowledge from subfields as diverse as drama and theatre, education, rehabilitation, orthopaedics, sport sciences, public health and social psychology.

Apart from the SSH, the applied sciences represent the only other domain in which the proportion of highly interdisciplinary papers is above expectation. This finding might suggest that research drawing on a broad range of a priori disconnected knowledge can indeed spur the emergence of novel technologies (i.e., new products or processes) as applied research is closer to innovation than the more fundamental research performed in the natural or health sciences. In fact, the results at the level of the most publishing ERA and non-ERA universities support this hypothesis since technical universities were found to be over-represented among the median scores of the selected set of organisations, whereas the other universities showed the opposite pattern. Although ERA universities did not do as well as non-ERA universities generally, technical universities within the ERA were highly over-represented above the median. The lower score of ERA universities in aggregate is therefore attributable to the non-technical universities. It is somewhat intriguing why such a strong dichotomy is not observed outside the ERA between technical and non-technical universities. Nevertheless, these results suggest that the emphasis placed on interdisciplinary collaboration in the context of Horizon 2020 could boost Europe’s innovation capabilities.

However, given the important limitations faced in this study (i.e., biases potentially incurred from coverage issues of the cited literature) and the general recognition that the measurement of interdisciplinary research is still challenging (Wagner et al., 2011), further research—using the metric presented in this paper and alternative ones—is required to deepen our understanding of the relationship between interdisciplinarity and, for example, research impact, excellence and innovation. For instance, our experiments (not detailed in this paper), have shown that the limitations detailed previously apply in the WoS as well, and that the indicator yields inconsistent results with slight alterations to the correction method (to remove biases) when ranking entities (e.g., countries, organisations). Yet, as shown above, it provides consistent results to study patterns across different types of entities. Other approaches relying on the disciplinary mix observed among the departmental affiliations of the authors as well as on a semantic analysis of scientific papers might yield more satisfactory results, which are essential towards developing an indicator suitable to benchmark entities.

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