Journal subject classification: intra- and inter-system discrepancies in Web Of Science and Scopus

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Abstract

Journal classification into subject categories is an important aspect in scholarly research evaluation as well as in bibliometric analysis. Journal classification systems use a variety of (partially) overlapping and non-exhaustive subject categories which results in many journals being classified into more than a single subject category. As such, discrepancies are likely to be encountered within any given system and between different systems. In this study, we set to examine both types of discrepancies in the two most widely used indexing systems - Web Of Science and Scopus. We use known distance measures, as well as logical set theory to examine and compare the category schemes defined by these systems. Our results demonstrate significant discrepancies within each system where a higher number of classified categories correlates with increased range and variance of rankings within them, and where redundant categories are found. Our results also show significant discrepancies between the two systems. Specifically, very few categories in one system are “similar” to categories in the second system, where “similarity” is measured by subset & interesting categories and minimally covering categories. Taken jointly, our findings suggest that both types of discrepancies are systematic and cannot be easily disregarded when relying on these subject classification systems.

Keywords: Journal subject classification · Scientometrics · Ranking · set theory · variance

1 Introduction

Journal classification into subject categories is an important aspect of the journal indexing systems. From a theoretical perspective, this classification is an external expression of the internal structure of science and thus, it can foster research on the inherent relationships between scientific fields, institutes and researchers as well as many others scientometric phenomena. From a practical perspective, this classification is often used by researchers in order to find information related to their field of work and allows one to avoid sifting through possibly many irrelevant journals. Universities and other institutions also rely on these subject categories for their evaluation and, in many cases, request their researchers to publish their works in journals in a specific set of classifications or in journals which are highly ranked in their classified subject categories. In many cases, researchers are mainly evaluated based on the articles they published in high ranking journals (e.g., top 25% of the journals in a subject category) (Dennis et al., 2006; McKiernan et al., 2019; Rice et al., 2020).

Unfortunately, classifying journals into subject categories is an ill-defined problem since the delineation of a scientific field of research is, itself, unclear and journals’ boundaries need not necessarily align with those of any given field of study. Several key challenges include interdisciplinarity, multipisciplinarity and the dynamic nature of scientific enquiry (Zitt et al., 2019). While various frameworks for the delineation have been proposed in the past (e.g., Hammarfelt et al. (2017)), these differ in the structure of the classification, its granularity, semantic aspects and additional parameters (see Waltman and van Eck...).
As such, major indexing services such as Web of Science (WoS), Scopus and others developed their own unique journal subject classification systems. Journal classification systems use a variety of (partially) overlapping and non-exhaustive subject categories. This results in many journals being classified into more than a single category. As a result, various discrepancies are likely to be encountered within any given system and between different systems. The journal subject classification systems of WoS and Scopus are widely used in practice and thus play a central role in the academic community. As such, in this work, we focus on their two journal subject classification systems and examine the intra-system (within each system) and inter-system (between the two systems) discrepancies.

We speculate that these discrepancies are not anecdotal, but in fact are systematic and encompass various scientometric phenomena. Specifically, we set the following research questions:

- How is the number of categories a journal is classified to associated with that journal’s impact metrics and rankings? We hypothesize that an inverse association exists between the number of categories and the ranking metrics of a specific journal, where a higher number of categories a journal is classified to is indicative of lower ranking of the journal.

- To what extent do subject categories intersect within each system? We lay several hypotheses related to this question.
  1. We hypothesize that nearly all subject categories will exhibit an overlap in their classified journals with at least one other category (i.e., intersecting subject categories), and that the number of categories each category has overlaps with is high.
  2. Focusing on the size of the overlap, we hypothesize that only a small number of subject categories will exhibit a large overlap in their classified journals (i.e., intersecting subject categories with an overlap of > 85%).
  3. Following the two hypotheses detailed above we further hypothesize that each category’s journals can be minimally “covered” by a small number of categories (relative to the number of categories in the system).

- To what extent do subject categories intersect between the two examined systems? In this respect, we hypothesize that all subject categories in one system will exhibit a large overlap in their classified journals with at least one category from the second system and that each category in one system can be minimally “covered” by a very small number of categories from the second system. (i.e., categories across the two systems display strong similarity).

It is important to note that various works have examined different aspects of WoS and Scopus indexing services (most recently [Martín-Martín et al. (2021); Singh et al. (2021); Visser et al. (2021)]), separately and/or combined. However, the possible discrepancies within and between the two associated journal subject classification systems have received little attention. Existing literature in this realm has predominantly relied on citation analysis techniques to examine these discrepancies. As such, our work complements the existing knowledge and can be instrumental in understanding the impact these discrepancies can have on academic evaluation of researchers and their work. In addition, it can promote further scientometric enquiry, especially in field delineation and impact normalization challenges.

2 Background

Our work focuses on WoS and Scopus which are the two most influential and most researched scholarly indexing services. Both index various types of source titles such as journals, conference proceedings and books.

Starting with WoS, it has been traditionally considered a more reliable source for bibliometric analysis and extensive research has been conducted focusing on this index. Research analysing its journal subject classification system focused on the mapping of science and clustering based on its journal subject category classification system [Leydesdorff et al. (2013); Zhang et al. (2010)]. Other studies identified some of the problems associated this classification system. [Leydesdorff and Bornmann (2016)] showed that WoS subject
categories are insufficient for performing bibliometric normalization due to “indexer effects”. They focused on the two fields- “Library and Information Science” (LIS), which has a WoS subject category and “Science and Technology Studies” (STS) which does not, and performed a mapping of citation behavior for journals in these fields. Their results showed that normalization using these categories might seriously harm the quality of the evaluation. Haustein (2012) identified that WoS subject classification is controversial and problematic especially with regards to interdisciplinary fields due to the pigeonholing process taken when performing the classification. They claim that an alternative system to WoS subject classification is needed. In line with this recommendation, additional research by Perianes-Rodriguez and Ruiz-Castillo (2017); Shu et al. (2019) compared WoS journal level classification system with publication level classification systems. They concluded that publication level classification systems constitute a credible alternative to WoS classification system. Following these studies, Milojević (2020) presented a method for reclassification of WoS indexed articles into existing WoS categories as well as into 14 broad areas, based on the article references.

Turning to Scopus, which is a more recent indexing system, little research was done on its journal subject classification system. An early study by de Moya-Anegón et al. (2007) focused on Scopus journal subject distribution, geographical distribution, language of publication among other measures. Their analyses shows that Scopus has quite homogeneous global representation in nearly all areas except Arts and Humanities. This study was conducted only 3 years after Scopus started indexing journals. A recent longitudinal analysis by Bordignon (2019) observed the changes in number of categories per journal and number of journals per category. They showed an increase on average in both aspects and concluded that newly added sources have been assigned to more fields and sub-fields on average than those indexed before the time period examined. Their findings corroborate those found in Wang and Waltman (2016) which observed that Scopus journals are assigned to a large number of categories. Their analysis further identified some issues related to category naming including near identical names and categories which are labelled as “miscellaneous”. In Lazic et al. (2017) the authors compared Scopus subject classification with the official classification of social sciences in Croatia and found a significant difference in the classifications. Their results showed Scopus mis-classifies journals to social sciences subject categories despite them publishing almost exclusively works related to natural sciences or biomedicine.

Many studies have compared the two systems along with other indexing databases. The main focus of these studies were the accuracy of these databases. This accuracy was measured using the rankings both systems induced by ordering the retrieved publications in decreasing order of the number of citations (Bar-Ilan et al. 2007) or the citation links completeness and accuracy (Visser et al. 2021; Franceschini et al. 2016). These studies identified that both systems suffer from incompleteness and inaccuracy of citation links and incorrect transcription of author names and/or title. The work by Meho and Sugimoto (2009) compared Scopus and WoS using citations behavior focusing on Information Science researchers. Their findings show that when the analysis was based on small entities, such as journals and institutions, the scholarly impact measure produced by the two systems vary significantly, while analysis based on larger entities such as countries and research domains produced similar scholarly impact measure. They claimed that the need to use one or both indexing services will vary among research domains when used for assessing research impact.

Several studies analysed author related metrics generated from citations in these systems (Bar-Ilan 2008; Harzing and Alakangas 2016). In Bar-Ilan (2008) WoS, Scopus and Google Scholar (GS) were compared in terms of the h-index for a specific set of researchers. Their findings show that, except for a few cases, the differences in the h-indices between WoS and Scopus are not significant, but the differences between GS and the two other systems are much more considerable. Harzing and Alakangas (2016) performed a longitudinal cross-disciplinary comparison of the WoS, Scopus and GS. Their results show that using h-index with WoS as a data source, in Life Science and Sciences was on average nearly eight times higher than in Humanities.

Other studies compared these systems in respect to the coverage and distribution of journals and publications. These studies show that the difference in journal coverage between Scopus and WoS has grown over time and that differences in coverage result in variations in research output volumes, rank and global share of different countries (Singh et al. 2021; Jacso 2005; Mongeon and Paul-Hus 2016). In Mongeon and Paul-Hus (2016) the authors observed that there is an over representation of certain countries and languages both in WoS and Scopus journal coverage. In addition, they show that WoS and
Scopus journal coverage differ the most in Natural Science and Engineering and in Arts and Humanities fields. Bartol et al. (2014) showed that Scopus provides more records and more citations per record and, when focusing on disciplines, Scopus showed better coverage than WoS in Agriculture, Medical, and Natural Sciences and most noticeably in Engineering & Technology.

Turning to comparison of the journal subject category classification methodology used by both systems, Wang and Waltman (2016) performed a detailed comparison of the classification systems of WoS and Scopus based on citation relations, where they measured the “connectedness” of a journal in respect to its assigned category and to other categories based on the citation percentage. They observed that, on average, journals have significantly more categories assignments in Scopus than in WoS. Furthermore, in Scopus journals are assigned to categories with which they are only weakly connected much more frequently than in WoS. They conclude that WoS and especially Scopus tend to be too lenient in assigning journals to categories.

The analyses in the above studies were based upon citation analysis, thus exploring one aspect of the classification systems. In this work, we complement these findings by considering two additional aspects: First, we examine the association between the number of categories and the ranking of any journal across its assigned categories. We do this by leveraging known distance measures. Second, we investigate the relationship between categories in each system and across the two systems in respect to the journals contained in them. In order to perform this analysis we leverage the logical set theory. To the best of our knowledge, this approach is unique in the analysis of journal classification and has yet to be applied in this realm.

Mathematical Definitions

In this work, we use the following the mathematical definitions and notations. A journal subject classification system assigns each journal \( j_i \in J \) possibly more than a single category from the set \( C \). We denote the set of categories associated with journal \( j_i \) as \( C_i = \{ c_k \} \).

For each of the assigned categories \( c_k \), \( j \) may be ranked differently based on its impact measure – Journal Impact Factor (JIF, in WoS) or SCImago Journal Rank (SJR, in Scopus). We denote this ranking as \( j_i^{c_k} \) reading as journal \( j_i \)’s ranking in category \( c_k \). For our analysis, we consider the ranking as the journal’s percentile ranking in each of its classified categories. Thus, for each journal, we have a set of percentiles corresponding to its set of classified categories.

In order to evaluate possible differences in rankings across categories, we adopt two standard distance measures: Min-Max (MM) and Variance (VAR). The Min-Max of journal \( j_i \) is defined as follows:

\[
MM(j_i) = \max_{c_k} \{ j_i^{c_k} \} - \min_{c_k} \{ j_i^{c_k} \}
\]

In words, \( MM(j_i) \) is the difference between the highest and lowest percentile journal \( j_i \) is ranked to in any of its assigned categories. This measure captures the “range” of rankings associated with a specific journals. The Variance is defined as follows:

\[
VAR(j_i) = \frac{1}{|C|} \sum_{c_k} (j_i^{c_k} - \mu)^2
\]

In words, \( VAR(j_i) \) is the sum of squared distances from the mean of all percentiles journal \( j_i \) is ranked to in all of its assigned categories, divided by the number of categories it is assigned to. This measure captures the variance in rankings associated with a specific journal— that is, how “noisy” are the rankings of a journal across its assigned categories.

Our study leverages different aspect of the logical set theory (Cantor, 1874). Set theory is a branch of mathematical logic that studies the characteristics and relations between collections of objects. In this work, we consider sets of journals and, separately, sets of categories as needed.

Let \( A \) and \( B \) be sets. We use the following operations (Kolmogorov and Fomin, 1975):

- **Union** - The set of all members of \( A, B \), or both, denoted \( A \cup B \)
- **Subset and Superset** - set \( A \) is a subset of set \( B \) if all members of \( A \) are also members of \( B \), denoted \( A \subseteq B \). if \( A \subseteq B \) than \( B \) is a superset of \( A \) denoted \( B \supseteq A \)
• Equivalence - if \( A \subseteq B \) and \( B \subseteq A \) then \( A \) is equivalent to \( B \), denoted \( A = B \).
• Intersection - the set all members of \( A \) which are also members of \( B \), denoted \( A \cap B \).
• Cover - a collection of sets \( (B, C, \ldots) \) excluding \( A \) is said to cover \( A \) if all members of \( A \) are members of \( B \cup C \cup \cdots \). A “minimal cover” of \( A \) is the smallest number of sets needed to cover \( A \).

We are not the first to adopt set theory-based analysis in bibliometrics. Rodriguez-Sánchez et al. (2014) performed graph based analysis where categories are vertices and edges represent the shared journals. In Subochev et al. (2018) the authors proposed ranking journals using methods from social choice and set theories to define aggregation methods of existing metrics. Fuzzy sets theory was applied to bibliometric analysis in order to display the “fuzzy” nature of field delineation (Bensman 2001; Egghe and Rousseau 2002). In a study related to ours, Rons (2012) proposed a a normalization method based on partitioning WoS categories according on their intersecting journals, however, their focus was on adaptation of standard field normalization to an observed publication record. To the best of our knowledge, our study is the first study to apply the core set theory to the study of journals subject category classification systems.

3 Data Collection

Our study focused on WoS and Scopus indexing systems. From each of these systems we downloaded the complete set of the indexed journals, their associated categories and metrics as of end of 2020. Overall, 21,424 journals were extracted from WoS and 40,804 journals were extracted from Scopus. All associated metrics reflect the 2019 scores. We excluded journals which were showing as “discontinued” or “Inactive” in Scopus (WoS does not contain this data). The number of journals indexed in Scopus, which remained after this cleanup, was 25,751.

Since the two systems do not cover the same set of journals and one of the aims of our study is to perform a comparative analysis between the two, we focus only on journals which are indexed in both systems. To identify these journals, journals from both systems were matched primarily based on their ISSN. In cases where the ISSN did not provide a match, we used the journals’ e-ISSN as a secondary matching criteria. Finally, for the very few cases not matched by ISSN or e-ISSN, we used the name as a matching criteria. The name matching was done as case insensitive exact matching. In addition, journals which did not have a scientometric score in either of the systems were further excluded from the analysis. The final set of journals for our analysis comprised of 13,247 journals with 254 categories in WoS and 327 categories in Scopus. 8,177 journals from WoS and 12,504 journals from Scopus which were not matched by these identifiers were removed from further consideration.

Table 1 summarizes the general statistics for each of these systems and of the data set used in the analysis. The descriptive statistics of mean, SD and median in Table 1 were calculated on the sets of journals and categories under analysis.

All data and code is available in GitHub under Journals Subject Classification.

4 Data Analysis

4.1 Intra-System Analysis

In this part, we analysed each of the two systems separately along the following criteria.

Journals distribution. In the first part of the analysis, we identified the distribution of journals within categories. As can be seen from Figure 1 in both WoS and Scopus, ~40 categories contain a small number of journals, ranging from 6-21 journals in WoS and 1-16 in Scopus. We can further see that the number of categories containing a large number of journals quickly decreases in both systems. Looking at the smallest and largest categories in both systems, Scopus has a significantly larger number of both small categories.
### Descriptive Statistics

|                        | WoS  | Scopus |
|------------------------|------|--------|
| Number of categories   | 254  | 327    |
| Total number of journals | 21,424 | 40,804 |
| Number of journals analysed | 13,247 | 13,247 |
| Mean number of journals per category | 83.67 | 94.28 |
| SD number of journals per category | 68.7 | 107.7 |
| Median number journals per category | 63 | 67 |

|                        | Mean number of subject categories assigned to each journal | SD number of subject categories assigned to each journal | Median number of subject categories assigned to each journal |
|------------------------|----------------------------------------------------------|--------------------------------------------------------|----------------------------------------------------------|
|                        | 1.58                                                      | 0.78                                                    | 1                                                       |
|                        | 2.34                                                      | 1.28                                                    | 2                                                       |

Table 1: General statistics

### Table 2: Small categories in Web Of Science and Scopus, less then 10 journals in category

| Category | Scopus Num Journals | Category | Web Of Science Num Journals |
|----------|---------------------|----------|----------------------------|
| Dental Hygiene | 1 | Literature, African, Australian, Canadian | 6 |
| Nurse Assisting | 1 | Andrology | 8 |
| Drug Guides | 1 | Dance | 8 |
| Emergency Medical Services | 1 |
| Podiatry | 1 |
| Immunology and Microbiology (miscellaneous) | 1 |
| Pharmacology (nursing) | 2 |
| Review and Exam Preparation | 2 |
| Assessment and Diagnosis | 3 |
| Care Planning | 3 |
| Chiropractics | 3 |
| Optometry | 4 |
| Pharmacology, Toxicology and Pharmacuetics (misc) | 4 |
| Complementary and Manual Therapy | 4 |
| Pharmacy | 5 |
| Fundamentals and Skills | 5 |
| General Health Professions | 6 |
| Equine | 6 |
| Research and Theory | 6 |
| Chemical Health and Safety | 7 |
| Veterinary (miscellaneous) | 7 |
| Dentistry (miscellaneous) | 7 |
| Periodontics | 8 |
| Health Professions (miscellaneous) | 8 |
| Medical and Surgical Nursing | 9 |
| Pediatrics | 9 |
| Critical Care Nursing | 9 |
| Occupational Therapy | 9 |
| Emergency Nursing | 9 |
| Nursing (miscellaneous) | 9 |
Table 3: Large categories in Web Of Science and Scopus—more than 350 journals in category

| Category                                      | Num Journals | Category          | Num Journals |
|-----------------------------------------------|--------------|-------------------|--------------|
| Electrical and Electronic Engineering         | 352          | Economics         | 372          |
| Cultural Studies                              | 402          |                   |              |
| Education                                     | 410          |                   |              |
| Ecology, Evolution, Behavior and Systematics  | 442          |                   |              |
| Literature and Literary Theory                | 448          |                   |              |
| History                                       | 532          |                   |              |
| Sociology and Political Science               | 537          |                   |              |
| General Medicine                              | 1139         |                   |              |

Figure 1: Number of journals contained in each category. X-Axis is the number of journals (in bins of 15), Y-Axis is the number of categories containing the associated number of journals.

and large categories than WoS. This may be due to its higher number of total categories. Tables 2 and 3 display categories containing less than 10 journals in each system and those containing more than 350 journals in each category. It can be observed that while no category in WoS had less than 6 journals and only 3 categories had less than 10 journals, Scopus had 8 categories containing a single or two journals and 30 categories had less than 10 journals. Similarly, the largest category in WoS had 372 journals, while 8 categories in Scopus had more than 350 journals and the largest category had 1139 journals, almost 10% of all analysed journals. These results seem to align with the statistics displayed in Table 1, specifically, the large SD in Scopus.

Categories distribution. We examine at the number of categories each journal was classified to. Figures 2a and 2b display the number of categories any single journal is classified to. It can be seen that, in WoS, the number of categories each journal is classified to decreases quickly, with most journals being classified to a single category and the highest number of classifications for a single journal is 6. In Scopus, however, more than 4,000 journals are classified in two categories (approximately a third of all journals under analysis), with one journal being classified to 11 different categories.

Categories and Journals’ Metrics. In order to understand how the scientometric scores of journals is related to the journals subject classifications in each system, we calculated the descriptive statistics of the JIF score for every journal in WoS and SJR score for every journal in Scopus, respectively. We then analysed these values in respect to the number of categories each journal was classified to. The results are displayed in Figure 3 and show the scientometric statistics by number of categories. Specifically, the top parts of the figure display the highest score in respect to the number of categories. The box plots in the bottom part of the figure show the quartile values of the scientometric measure, extending from Q1 to Q3, with an horizontal line at the median (Q2). The whiskers extend from the edges of the box.
to show the range of the data up to 1.5 times the inter quartile range. The △ shows the mean of the scientometric measure. In WoS, we can see that the highest JIF ranking decreases with the number of categories assigned to a journal, while all other statistics display an opposite trend, increasing with the number of categories a journal is classified to. In Scopus, only a single journal is classified into 11 categories and no journal is classified into 10 categories, thus we omit this journal in the following analysis. Observing the classification of up to 9 categories, the highest SJR score shows a similar behaviour to that observed in WoS, namely decreasing with the number of categories. However, all other metrics displayed do not show any clear upward or downward trend. This means that while for WoS higher number of categories is associated with higher metric score on average, this is not the case for Scopus. This could possibly be explained by the nature of the categories associated with the journals, specifically that in WoS the categories associated with a journal display similar citation pattern, while those in Scopus do not.

Following these observations, we further wanted to understand the relation between the number of categories a journal is classified to and the differences in rankings among these categories. To that end, we evaluated the MM and VAR (see Section 2) as functions of the number of classified categories. Recall that the MM is the size of the range of the rankings across the categories a journal is classified to while the VAR is the variance in these rankings. Figures 4 and 5 display the findings. The box plots in the figures extend from Q1 to Q3 quartile values for the MM and VAR of the percentile rankings, with a horizontal line at the median (Q2). The whiskers extend from the edges of the box to show the range of the data up to 1.5 times the inter quartile range. The △ shows the mean of the respective MM and VAR functions. As can be seen, WoS shows an increase in both MM and VAR as the number of categories increases up to five categories and a decrease for 6 categories classification. Scopus shows a small yet consistent increase in both the MM and VAR as the number of classified categories increases. This means that as the number of categories any single journal is classified to, its range of rankings as well as the variance within this range, tends to increase. To verify our observations, we calculated the Pearson’s correlation on both the MM and VAR measures with respect to the number of classified categories, both for WoS and Scopus. In both WoS and Scopus results were weakly positive yet significant for the MM (WoS: r=0.26, p<0.001; Scopus: r=0.313, p<0.001) and for the VAR (WoS: r=0.08, p<0.001; Scopus: r=0.08, p<0.001). Overall, Scopus displays a stronger effect size than WoS as can be seen from both the plots and the statistical correlation.

**Relations between Categories.** In this part of the analysis, we focus on the following possible relationships between subject categories: equivalent categories, subset and superset categories and intersecting categories as defined in Section 2.

Starting with WoS, we found that it has no equivalent categories and no subset categories. The number of categories with an intersection with at least one other category in WoS is 252 - 99.2% of all WoS categories. Specifically, only 2 categories have no intersection with any other category. These are:

- “Dance”, number of journals: 8
Figure 3: highest scientometric score and q1 - q3 range of scientometric scores

Figure 4: MM of percentile rankings per number of categories

Figure 5: VAR of percentile rankings per number of categories
• “Literature, African, Australian, Canadian”, number of journals: 6

These categories are two of the three smallest categories as can be seen in Table 2. Turning to Scopus, again, no equivalent categories were found. However, 7 superset categories and 12 subset categories were found. The number of categories with an intersection with at least one other category is 325 - 99.4% of all Scopus categories. Identically to WoS, only 2 categories have no intersection with any other category. However, these two categories contain only a single journal:

• “Dental Hygiene”, number of journals: 1
• “Nurse Assisting”, number of journals: 1

Four categories are “pure” subsets of other categories, meaning that all journals in each of these categories appear only in these categories and in their superset categories. These are:

• “Podiatry”, number of journals: 1
• “Immunology and Microbiology (miscellaneous)”, number of journals: 1
• “Emergency Medical Services”, number of journals: 1
• “Drug Guides”, number of journals: 1

Note that these are all single-journal categories.

Figure 6 shows all subset categories in Scopus. As can be observed from the figure, the “Podiatry” category is a subset of three categories which, seemingly, are not related to it at all (“Language and Linguistics”, “Linguistics and Language” and “Computer Science Applications”). Figures 7a and 7b show the distribution of intersections of categories. While both WoS and Scopus show a similar distribution pattern, overall, Scopus categories intersect with many more categories. In WoS, no category intersect with more than 60 categories while, in Scopus, about 1/6 of the categories have intersections with over 60 other categories each, 7 categories have intersections with over 100 categories with the “General Medicine” category having intersections with over 200 categories.

Looking at the intersecting categories, we are also interested in identifying “similar” categories. In order to measure the “closeness” between two intersecting categories, we compute the intersection size and divide it by the size of the smaller category in that intersection. In WoS, only a single pair of categories had an intersection greater than 85%. This is shown in Figure 8. In Scopus, 6 pairs of categories had a “closeness” of above 80% with two pairs of categories displaying an intersection of over 90%, these are displayed in Figure 9.

Minimal Cover. Following our analysis of the intersecting and subset categories, we looked at the minimal cover as defined in Section 2. We performed this analysis for each category using all other categories in its system. That is, we examine which categories can be covered by other categories and what is the minimal number of such categories needed in order to cover it.

In WoS, only 6 categories could be fully covered (2%). All these categories consist of between 13 and 78 journals in each category. The minimal number of categories needed to cover each of these six categories ranged from 4 to 15. Based on the very low number of categories which could be covered, we can deduce that all the other categories in WoS (98%) had at least one journal which was classified solely to that specific category (and thus could not be covered by others). In Scopus, on the other hand, 56 categories (17%) could be fully covered. These categories consist of between 1 and 183 journals in each category. The minimal number of categories needed to cover each of these six categories ranged from 1 to 24. Recall that Scopus contains “pure” subset categories, thus these categories can be minimally covered by a single other category.

We further examine situations in which a category can be “almost” covered. Namely, we add a flexible threshold allowing for 95% cover of journals in a category and still consider it as “covered”. In WoS, 14 additional categories could now be covered (8%). The number of journals in each of these categories ranged from 13 to 193. The minimal number categories needed to cover these categories ranged from 5 to 39. In Scopus, 80 additional categories (41%) could now be covered, with number of journals ranging
Figure 6: Subsets of Scopus categories.

Figure 7: Number of intersecting categories per category

(a) WoS

(b) Scopus
Figure 8: intersect of WoS categories- closest categories, above 85%

Figure 9: intersect of Scopus categories- closest categories
from 1 to 375 journals. The minimal number of categories needed to cover each of these categories ranged from 1 to 56. Figure 10 displays the minimal cover in respect to the number of journals in each category and to the total number of categories needed to cover this category. Top plots display no threshold (i.e., full cover). Bottom plots display 95% cover.

It is evident from our results that lowering the threshold even by a small percentage leads to a fast increase in the number of categories which can be minimally covered, most notably for Scopus. As can also be seen from the plots, when lowering the threshold, the added categories with minimal cover are mostly those containing less than 100 journals. However, Scopus shows an increase also in the categories containing 100-300 journals. Furthermore, the apparent linear relation between the minimal cover size and the number of total covering categories which can be seen on the right hand side of Figure 10 (a) and (b) displays a larger incline in the 95% threshold case.
4.2 Inter-System analysis

In this part of the work we compare one system against the other. We begin by assuming that the journal subject classification given by one system is the “true” (or “correct”) one and analyse the second system against that classification. Then, we switch the roles between the two systems.

**Categories Distribution.** Following the analysis we performed in Section 4.1, we matched the number of categories assigned to each journal in WoS and Scopus. As the number of categories per journal in each system is not normally distributed, we use the Wilcoxon signed rank test (Wilcoxon, 1992) to compare the two systems. The results show that the number of categories assigned to a journal in Scopus was statistically significant higher than in WoS, (t=397962.5, p<0.001). The descriptive statistics are displayed in Table 1.

**Relations between categories.** In a similar fashion to the analysis done in 4.1, we examine subsets, supersets, intersecting or equivalent categories in respect to the shared journals between the two systems. Recall that, in this work, we consider only the journals indexed by both systems. Thus, all categories in one system had at least one intersection with at least one category in the other system.

Since no equivalent categories could be found between the two systems, we start by examining subset categories. Starting with WoS being considered as the “true” categorization, we identified 13 categories in WoS which have subsets in Scopus. When performing the same analysis starting with Scopus, 9 such subsets were found. Figures 11 and 12 display the subsets with more than a single journal in the subset. Again, the names of the categories are very indicative of their similarities.

Following our subset analysis, we now look at the intersections of categories across the two systems. Starting with WoS, we found 6 high intersecting categories with Scopus (see Figure 13). That is, 6 of WoS’s categories have an intersection greater than 95% with a category from Scopus. Turning to Scopus, we found only a single such category (see Figure 14). As can be observed from the names of the categories, these tend to display very similar meanings. The number of journals in the intersection of the large intersecting categories ranges from ~60 to ~140.

**Similar Categories.** We now turn to identify “similar” categories in both systems. By similar categories we refer to categories which share a large percentage of journals. For each category in one system, we...
Figure 12: WoS categories as subsets of Scopus categories. Dark purple - Scopus categories, lilac and gray - WoS categories.

Figure 13: WoS to Scopus intersect, above 95%. Purple- WoS categories, Cyan - Scopus categories.

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Figure 14: Scopus to WoS intersect above 95%. Purple - Scopus category, Cyan - WoS category
identified all categories in the other system which had any shared journals (i.e., intersecting categories). Starting with a threshold of 5%, we measured how many categories in one system had an intersection larger than that threshold with another category in the the other system. The threshold was increased gradually in steps of 5% and the process was repeated until the maximum threshold of 100% (i.e., equivalent categories which we already establish do not exist). Then, we repeated the same process starting with the second system. The results are plotted in Figure 15 and show that for low thresholds, as can be expected, all categories in one system have “enough” shared journals with a category in the second system to be considered similar. It is evident from the figure that the blue line, representing Scopus categories which are similar to WoS categories is above the green line at all points in the plot. This means that starting with WoS categories and identifying similar Scopus categories, there will be more such categories at any threshold, then when starting with Scopus and identifying similar WoS categories. For example, when the threshold is set at 55%, ∼75% of WoS categories share journals at that threshold with Scopus categories, but less than 60% of Scopus categories share journals at that threshold with WoS categories. Our results lend themselves to the question of minimal cover - Could any category in one system be covered by two (or more) categories in the other system. This is examined next.

Minimal Cover. In this part of our analysis we looked at the minimal number of categories in one system that are needed in order to cover a single category in the second system. This analysis complements the analysis done in 4.1. We varied the threshold required for minimum cover starting with full coverage (100%) and gradually decreased it in step of 5%, thus relaxing the requirement for full coverage.

As a first step, we considered the entire set of journals under analysis in this study (13,247), as being categorized to a single “meta-category” in each system. That is, we examine how many categories are needed from one system in order to cover all journals in the other. Starting with WoS, the minimal cover set of categories from Scopus required to fully cover WoS is 279 (85% of the total Scopus categories). The minimal cover set with 95% threshold is 177 (54%) and with 90% threshold is 130 (40%). Turning to Scopus, the minimal cover set of categories from WoS required to fully cover Scopus is 248 (98% of WOS categories). The minimal cover set with 95% threshold is 182 (72%) and with 90% threshold is 140 (55%). Taken jointly, these results indicate that the number of categories required to cover all journals in one system by the other is similar for both systems. In Scopus, it seems that a large number of categories (almost 50) is “redundant” in the sense that those are not needed in order to fully cover the set of journals in WoS. In fact, 279 categories are needed to fully cover WoS, which is quite close to the number of categories in WoS - 254. However, the reverse is not true. Almost all WoS categories were needed in order to cover Scopus journals.

Similarly to the analysis we have done in Section 4.1 for each system separately, we set to examine the minimal cover required for *every category* in one system by the second system. For each category in one system, we found the minimal set of categories from the second system required in order to cover all journals in that category. Starting with WoS, the minimal number of cover categories from Scopus...
required to cover each single WoS category ranged from 1 to 26. Similarly, when covering all categories from Scopus with categories from WoS the minimal number of cover categories from WoS required to cover a single Scopus category ranged from 1 to 98. We varied the threshold for cover from full coverage (100%) to partial coverage at 95% and 90%. From Figure 16 it can be seen that as the threshold varies, the number of categories requiring a high minimal cover quickly decreases, as can be expected. This is more evident in Scopus, where, without a relaxed threshold, one category requires almost 100 (40%) of WoS categories to cover it, but with the 90% threshold the number of categories required to cover any category in it is at most 53 (20%). Covering WoS, the minimal cover set from Scopus ranges up to 26 (0.08%) categories without a relaxed threshold and up to 15 (0.045%) with 90% threshold. Figure 17 displays the cumulative minimal cover needed for each system and as can be seen from it WoS and Scopus show similar trend where the 90% threshold plot increases quickly at the lower cover set size. For WoS, without a threshold ~80% of the categories can be covered by a maximum of 10 categories from Scopus. With a 90% threshold ~80% of the categories can be covered by a maximum of 5 categories and almost all 254 categories can be covered by 10 categories. Scopus shows a similar, although weaker, trend as ~80% of its categories can be covered by 15 categories from WoS without a threshold. With a 90% threshold ~80% of the categories can be covered by a maximum of 8 categories from WoS.

For both systems, we also looked at how the size of the minimal cover set is related to the number of journals in each category and to the total number of covering categories from the other system. Figure 18 displays the results. It is noticeable that categories with relatively small number of journals (less than 200) can be covered by ~10 categories from the second system. Furthermore, a linear relation between the minimal cover size and the number of total covering categories can be seen on the right hand side of the Figure. Due to the dense display, in Figure 19 we focus on categories with very low number of journals (20 or less) and on those with very low number of covering categories. In this narrow perspective no clear trend, between the size of the minimal cover and the number of journals, emerges. However, our analysis shows that despite the very low number of journals, the categories in either system can not be covered by single or dual categories from the second system. E.g- WoS contains 28 small categories, 9 require more than 3 categories from Scopus to cover them and 1 category requires 7 Scopus categories to cover it. Scopus contains 56 small categories, 24 requiring a cover set of more than 3 categories from WoS and 1 category requires 11 categories from WoS to cover it. The same holds true in respect to the total number of covering categories. It is more evident for Scopus, where, as we have discussed before, the number of categories with low number of journals classified to them is much larger than in WoS. This could indicate that some of these small categories may contain multidisciplinary journals requiring multiple categories to cover them. Figure 20 focuses on the categories with high minimal cover and shows that only a small number of WoS categories can be minimally covered by a relatively high number of categories from Scopus, even when the number of journals or the total number of covering categories is high (blue dots in the figure). For Scopus this is not the case as we can see categories with less than 200 journals covered by a large set of WoS categories (green dots in the figure).
Figure 17: Cumulative Minimal cover

(a) WoS

(b) Scopus

Figure 18: Match between WoS categories and Scopus categories. Minimum Scopus categories covering single WoS category and minimum WoS categories covering single Scopus category. Outliers removed.
Figure 19: Match between WoS categories and Scopus categories. Minimum Scopus categories set covering a single WoS category and minimum WoS categories covering a single Scopus category. Categories with 20 journals or less and with corresponding 10 categories or less are shown.

Figure 20: Match between WoS categories and Scopus categories. Minimum Scopus categories set covering a single WoS category and minimum WoS categories covering a single Scopus category. Outliers focus-only categories with high minimal cover are shown.
5 Conclusion and Discussion

In this study we have analysed the journal subject classification systems in WoS and Scopus indexing services. We employed two types of analysis to address our research questions: intra-system analysis, in which each system was examined separately, and inter-system analysis, in which both systems were compared against each other.

From the intra-system analysis perspective, our analysis showed that while the distribution pattern of journals in categories in both systems is similar, in Scopus a significant number of categories contain an extremely small number of journals or an extremely large number of journals. Notably, in WoS, no category contains less than 6 journals or more than 400 journals while, in Scopus, 16 categories contain less than 6 journals and 7 categories contain over 400 journals. Both very small and very large categories could lead to adverse outcomes when used for field normalization or ranking of journals. For example - ranking a journal in a very small category does not provide any meaningful value while performing the same in a very large category renders the difference between two closely ranked journals negligible.

In order to answer our first research question, we focused on the most frequently used scientometric scores, the JIF and SJR scores, and analysed how these scores and the rankings they induce within a category relate to the number of categories a journal is classified to. Our findings show that while the maximum score a journal receives decreases with number of categories that journal is classified to, this is not the case when observing the other statistics of these metrics, especially in regards to JIF. Our findings suggest that in WoS- the mean, median and Q1 to Q3 quantile JIF score increases as the number of categories a journal is classified to increases. Scopus does not display this upward trend. When examining our distance metrics, we see a positive correlation between the ranking range (as captured by the MM) and the number of categories the journal is classified to. This finding suggests that the more categories the journal is classified to the larger the range of its rankings. In terms of variance in each journal’s rankings (as measured by VAR), a weak yet significant correlation between the VAR and the number of categories was found, meaning that a higher number of categories a journal is classified to is marginal indicative of higher variance of ranking across these categories. Combined, these results suggest that as the number of categories a journal is classified to increases, not only is the the range of ranking higher, but that within this range a larger variance is expected. Namely, while a journal is singly given a value (JIF or SJR), the ranking induced by this single value varies greatly across categories and the variation increases as the number of assigned categories increases. This variation in rankings across categories could be exploited to “pick and choose” the “best” ranking among the assigned categories.

To answer our research questions related to categories similarities, we focused on the set theory relationships detailed in Section 2. Our analysis showed that in either system, no equivalent categories exist, however in each system two of the smallest categories were “standalone” categories, meaning that the journals classified to them were not classified to any other category. The extremely small categories and the single classification of journals in these categories renders the usage of scientometric measures of the journals in them pointless. Ranking a very small number of journals, or at worst, a single one in the only category they are classified to cannot provide a an adequate indication of their merit. While, in both systems, other small categories exist, the journals there are classified to additional categories in the same system and could be scientometrically evaluated in the other, significantly larger, categories. Our subset analysis of each system shows that while WoS had no pure subsets, Scopus had numerous such categories and notably, one of these categories, Podiatry, had a single journal and was a subset of three different categories, none of them related to Podiatry. Again, from the low number of journals and due to these categories being pure subsets of other, significantly larger, categories, evaluating the journals in respect to the small categories is not meaningful. The larger categories which are supersets of these categories could potentially give a more meaningful ranking of the journals assigned to them. Surprisingly, looking at the largest categories of each system, WoS has no categories which are supersets and Scopus categories which are supersets are not the large categories we observed in Table 3 except for “Education”.

Turning to the intersection of categories, our findings show that all of the large categories except the “Literature and Literary Theory” category have an intersection with a high percent of categories- 20% of all categories. This seems to indicate that these categories contain journals from a large diversity of research fields and are in fact multidisciplinary or interdisciplinary. Previous research in respect to such categories had already observed the problems associated with using scientometrics to evaluate journals in

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these categories, e.g (Haustein, 2012). This is especially true if the metrics are source normalized as the normalization is often based on field of research.

Analysing the percentage of journals in the intersecting categories, we can see a few categories which have a very high percentage of intersection, especially in Scopus. The high intersection renders the categories as either almost identical as is the case in “Language and Linguistics” and “Linguistics and Language” or as one category being a subset of the other category (such as in “Radiological and Ultrasound Technology” and “Radiology, Nuclear Medicine and Imaging”). The near identity of some categories in Scopus was also observed in Wang and Waltman (2016), but their findings were based on the name similarity, while our findings corroborate these by focusing on the journals associated with those categories. Turning to the two categories which have no intersection at all, it is unclear why the single “Dental Hygiene” journal is not categorized under “Dentistry (miscellaneous)”. A similar argument holds for “Nurse Assisting” which its single journal could be categorized under “Nursing (miscellaneous)” or “Critical Care Nursing”.

Taken together, all of the above findings point to a subset of categories which provide little to no meaning when ranking journals. These categories are too small, too redundant and utilizing existing scientometrics to evaluate their journals is not likely to bring about valuable insights.

Our minimal cover set analysis showed that in WoS 98% of categories could not be covered completely. We can conclude that all of these categories had at least one journal which was classified only to them. Scopus showed different behavior when nearly 1/6 of its categories could be covered. While this contradicts our original hypothesis, this could be expected from both systems as was observed before in Figure 2.

Recall that WoS has very large number of journals which are classified to a single category and, in contrast, the majority of journals in Scopus which are multi-classified. Relaxing the threshold required for minimal cover to 95% shows a near linear relation between the minimal cover size and the number of journals and, similarly, between the minimal cover size and the total number of covering categories. This suggests that a higher number of covering categories is indicative of a small number of shared journals between each of the categories and the category covered.

Turning our focus to the inter-system analysis, the results corroborate previous findings showing that journals are classified to statistically significantly higher number of categories in Scopus than in WoS. Viewing the shared journals across categories in the two systems shows an almost linear decrease in number of shared journals as the requirement threshold increases, which is expected as we require a higher percentage of shared journals per category. This is true both when considering WoS as the “true” (i.e. originating) classification system and when considering Scopus as the “true” system. However, from Figure 15 we can see that using WoS as the “true” classification system, the decrease in shared journals is slow at first with almost 100% of the categories having 40% of journals shared with a “matching” Scopus category. This trend continues to be slower than the pattern shown when using Scopus as “true” classification system all the way to 90% shared journals threshold. These results indicate that Scopus does not provide a finer grained classification system compared to WoS, but rather a significantly different one.

Our analysis of the categories showed that, in both systems, a very small number of categories have a large percentage of shared journals. Considering a 95% intersection threshold, 6 WoS categories intersected with Scopus categories and one Scopus category intersected with a WoS category. A deeper look regarding the categories with the highest number of shared journals in the intersection shows that these indeed are similar categories as can be observed by their names. In some of these categories, the name is identical, while in the others they are highly similar. This is the case for “Cardiac & Cardiovascular Systems” in WoS and “Cardiology and Cardiovascular Medicine” in Scopus or “Literature, Romance” in WoS and “Literature and Literary Theory” in Scopus. Only the category “Ophthalmology” had a large intersection with the category from the second system twice, once when WoS was chosen as “true” classification system, and once when Scopus was chosen as such.

Following our intersection analysis we focused on categories in one system which are subsets of categories in the other system. Our findings showed that these subsets are either very small, containing only 1 or 2 journals, or are indeed sub categories within the larger categories. Such an example is the WoS category “Dentistry, Oral Surgery & Medicine” which is a superset of “Oral Surgery” and “Orthodontics”, which are two Scopus categories.

Finally we looked at the minimal number of categories in one system required to cover any single category in the other system. Due to the nature of our methodology, i.e., only journals which are indexed
in both systems were analysed, every category in one system is bound to be covered by categories from the other system. Observing the cumulative cover set with a varying threshold on the percentage of journals required for coverage, we can see that for both systems over 50% of the categories can be covered by 10 categories at most and as the threshold varies this number decreases.

Observing the small categories, with low number of journals or low number of covering categories from the second system show no specific trend in respect to the minimal number of categories required to cover them. Observing “outlier” categories, those which require a high number of categories to cover them, our findings show that even categories with a fairly low number of journals (<100) may require a high number of categories to minimally cover them. For WoS categories, ~25% of them are covered by at least 8 Scopus categories. More notably, for Scopus categories, ~50% of them are minimally covered by at least 8 WoS categories. As the minimal cover required is non negligible, these results further support our previous observation that Scopus does not provide a finer grained classification system compared to WoS.

We recognize that this study is limited in several respects. First, our selection and cleanup process as detailed in Section 3 could have missed identifying journals with slightly different names or added incorrect ones. However, we have performed a manual analysis of some of the journals in order to mitigate this issue as much as possible. In addition, while our study was comprised of a very large set of journals, encompassing an extensive variety of research fields, it contained only the subset of journals indexed by both systems. Thus our findings are on the one hand limited to the journals and categories under analysis, but allow for a more accurate and succinct comparison. The metrics used in our analysis were the JIF and SJR. These two metrics are calculated differently and could be a confounding factor in our ranking analysis and comparison. However, previous studies have shown the correlation of these metrics (Subochev et al., 2018). Finally, our analysis did not consider additional metrics which are normalized utilizing different normalization approaches. In future studies we would like to see how such normalization techniques correlate to ranking across categories. Some interesting questions in this area arise: How would the difference in ranking look like when using normalized metrics such as SNIP? Will this difference be consistent? In this aspect the new Journal Citation Indicator from WoS would could be compared to current metrics. Another aspect which we wish to further explore will be to combine our analysis with citation based analysis in order to gain a more complete perspective. Finally, we wish to further expand our studies to include additional indexing systems such as Dimensions and Microsoft Academic.

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6 References

References

Archambault, É., Beauchesne, O. H., and Caruso, J. (2011). Towards a multilingual, comprehensive and open scientific journal ontology. In Proceedings of the 13th international conference of the international society for scientometrics and informetrics, pages 66–77. Durban South Africa.

Bar-Ilan, J. (2008). Which h-index?—a comparison of wos, scopus and google scholar. Scientometrics, 74(2):257–271.

Bar-Ilan, J., Levene, M., and Lin, A. (2007). Some measures for comparing citation databases. Journal of Informetrics, 1(1):26–34.

Bartol, T., Budimir, G., Dekleva-Smrekar, D., Pusnik, M., and Juznic, P. (2014). Assessment of research fields in scopus and web of science in the view of national research evaluation in slovenia. Scientometrics, 98(2):1491–1504.

Bensman, S. J. (2001). Bradford’s law and fuzzy sets: Statistical implications for library analyses. IFLA journal, 27(4):238–246.

Bordignon, F. (2019). Tracking content updates in scopus (2011-2018): a quantitative analysis of journals per subject category and subject categories per journal. In ISSI, pages 1630–1640.

Cantor, G. (1874). Ueber eine eigenschaft des inbegriffs aller reellen algebraischen zahlen. Journal für die reine und angewandte Mathematik, 77:258–262.

de Moya-Anegón, F., Chinchilla-Rodríguez, Z., Vargas-Quesada, B., Corera-Álvarez, E., Muñoz-Fernández, F., González-Molina, A., and Herrero-Solana, V. (2007). Coverage analysis of scopus: A journal metric approach. Scientometrics, 73(1):53–78.

Dennis, A. R., Valacich, J. S., Fuller, M. A., and Schneider, C. (2006). Research standards for promotion and tenure in information systems. Mis Quarterly, pages 1–12.

Egghe, L. and Rousseau, R. (2002). A proposal to define a core of a scientific subject: A definition using concentration and fuzzy sets. Scientometrics, 54(1):51–62.

Franceschini, F., Maisano, D., and Mastrogiacomo, L. (2016). Empirical analysis and classification of database errors in scopus and web of science. Journal of Informetrics, 10(4):933–953.

Hammarfelt, B., Åström, F., and Hansson, J. (2017). Scientific publications as boundary objects: theorising the intersection of classification and research evaluation. In Information research, volume 22.

Harzing, A.-W. and Alakangas, S. (2016). Google scholar, scopus and the web of science: a longitudinal and cross-disciplinary comparison. Scientometrics, 106(2):787–804.

Haustein, S. (2012). Multidimensional journal evaluation: Analyzing scientific periodicals beyond the impact factor. Walter de Gruyter.

Jacso, P. (2005). As we may search—comparison of major features of the web of science, scopus, and google scholar citation-based and citation-enhanced databases. Current science, 89(9):1537–1547.

Kolmogorov, A. N. and Fomin, S. V. (1975). Introductory real analysis. Courier Corporation.

Lazić, N., Jokić, M., and Mateljan, S. (2017). Reliability of scopus subject classification of journals and its impact on bibliometric research.

Leydesdorff, L. and Bornmann, L. (2016). The operationalization of “fields” as wos subject categories (wc s) in evaluative bibliometrics: The cases of “library and information science” and “science & technology studies”. Journal of the Association for Information Science and Technology, 67(3):707–714.
Leydesdorff, L., Carley, S., and Rafols, I. (2013). Global maps of science based on the new web-of-science categories. *Scientometrics*, 94(2):589–593.

Martín-Martín, A., Thelwall, M., Orduna-Malea, E., and López-Cózar, E. D. (2021). Google scholar, microsoft academic, scopus, dimensions, web of science, and opencitations’ coci: a multidisciplinary comparison of coverage via citations. *Scientometrics*, 126(1):871–906.

McKiernan, E. C., Schimanski, L. A., Nieves, C. M., Matthias, L., Niles, M. T., and Alperin, J. P. (2019). Meta-research: use of the journal impact factor in academic review, promotion, and tenure evaluations. *Elife*, 8:e47338.

Meho, L. I. and Sugimoto, C. R. (2009). Assessing the scholarly impact of information studies: A tale of two citation databases—scopus and web of science. *Journal of the American Society for information science and technology*, 60(12):2499–2508.

Milojević, S. (2020). Practical method to reclassify web of science articles into unique subject categories and broad disciplines. *Quantitative Science Studies*, 1(1):183–206.

Mongeon, P. and Paul-Hus, A. (2016). The journal coverage of web of science and scopus: a comparative analysis. *Scientometrics*, 106(1):213–228.

Perianes-Rodriguez, A. and Ruiz-Castillo, J. (2017). A comparison of the web of science and publication-level classification systems of science. *Journal of Informetrics*, 11(1):32–45.

Rice, D. B., Raffoul, H., Ioannidis, J. P., and Moher, D. (2020). Academic criteria for promotion and tenure in biomedical sciences faculties: cross sectional analysis of international sample of universities. *Bmj*, 369.

Rodriguez-Sánchez, R., García, J. A., and Fdez-Valdivia, J. (2014). Evolutionary games between subject categories. *Scientometrics*, 101(1):869–888.

Rons, N. (2012). Partition-based field normalization: An approach to highly specialized publication records. *Journal of Informetrics*, 6(1):1–10.

Shu, F., Julien, C.-A., Zhang, L., Qiu, J., Zhang, J., and Larivière, V. (2019). Comparing journal and paper level classifications of science. *Journal of Informetrics*, 13(1):202–225.

Singh, V. K., Singh, P., Karmakar, M., Leta, J., and Mayr, P. (2021). The journal coverage of web of science, scopus and dimensions: A comparative analysis. *Scientometrics*, 126(6):5113–5142.

Subochev, A., Aleskerov, F., and Pishlyakov, V. (2018). Ranking journals using social choice theory methods: A novel approach in bibliometrics. *Journal of Informetrics*, 12(2):416–429.

Visser, M., van Eck, N. J., and Waltman, L. (2021). Large-scale comparison of bibliographic data sources: Scopus, web of science, dimensions, crossref, and microsoft academic. *Quantitative Science Studies*, 2(1):20–41.

Waltman, L. and van Eck, N. J. (2019). Field normalization of scientometric indicators. In *Springer handbook of science and technology indicators*, pages 281–300. Springer.

Wang, Q. and Waltman, L. (2016). Large-scale analysis of the accuracy of the journal classification systems of web of science and scopus. *Journal of informetrics*, 10(2):347–364.

Wilcoxon, F. (1992). Individual comparisons by ranking methods. In *Breakthroughs in statistics*, pages 196–202. Springer.

Zhang, L., Liu, X., Janssens, F., Liang, L., and Glänzel, W. (2010). Subject clustering analysis based on isi category classification. *Journal of Informetrics*, 4(2):185–193.

Zitt, M., Lelu, A., Cadot, M., and Cabanac, G. (2019). Bibliometric delineation of scientific fields. In *Springer Handbook of Science and Technology Indicators*, pages 25–68. Springer.