RESEARCH ARTICLE

Practical method to reclassify Web of Science articles into unique subject categories and broad disciplines

Staša Milojević

Center for Complex Networks and Systems Research, Luddy School of Informatics, Computing, and Engineering, Indiana University, Bloomington

an open access journal

Check for updates

Citation: 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. https://doi.org/10.1162/qss_a_00014

DOI: https://doi.org/10.1162/qss_a_00014

Received: 17 July 2019
Accepted: 03 December 2019

Corresponding Author:
Staša Milojević
smilojev@indiana.edu

Handling Editor:
Ludo Waltman

Keywords: classification

ABSTRACT

Classification of bibliographic items into subjects and disciplines in large databases is essential for many quantitative science studies. The Web of Science classification of journals into approximately 250 subject categories, which has served as a basis for many studies, is known to have some fundamental problems and several practical limitations that may affect the results from such studies. Here we present an easily reproducible method to perform reclassification of the Web of Science into existing subject categories and into 14 broad areas. Our reclassification is at the level of articles, so it preserves disciplinary differences that may exist among individual articles published in the same journal. Reclassification also eliminates ambiguous (multiple) categories that are found for 50% of items and assigns a discipline/field category to all articles that come from broad-coverage journals such as *Nature* and *Science*. The correctness of the assigned subject categories is evaluated manually and is found to be ∼95%.

1. INTRODUCTION

The problem of the classification of science has attracted the attention of philosophers and scientists alike for centuries (Dolby, 1979). The practice of classification is usually understood as a process of arranging things "in groups which are distinct from each other, and are separated by clearly determined lines of demarcation" (Durkheim & Mauss, 1963, p. 4). However, nature, and therefore science, with all its complexity, does not conform to any particular categorization or hierarchical structuring (Bryant, 2000) and there is no singular or perfect classification (Glänzel & Schubert, 2003). Despite inherent limitations, classifications are of practical use to organize and study knowledge. Many classification schemes of science and scientific literature have been proposed, with different levels of granularity and/or hierarchy. Different schemes have different levels of complexity and sophistication, and criteria can be constructed to compare and evaluate them (Rafols & Leydesdorff, 2009).

The classification of scientific literature has been pursued within quantitative science studies since at least the 1970s (e.g., Carpenter & Narin, 1973; Narin, Carpenter, & Berlt, 1972; Small & Griffith, 1974; Small & Koenig, 1977). A number of studies frame this research as discipline/field delineation or delimitation (Gläser, Glänzel, & Scharnhorst, 2017; Gómez, Bordons, Fernandez, & Méndez, 1996; López-Illescas, Noyons, Visser, De Moya-Anegón, & Moed, 2009; Zitt, 2015). The search for adequate solutions to classification has intensified in recent years, often motivated by finding appropriate reference sets for citation normalization needed for evaluation studies (Bornmann, 2014; Glänzel & Schubert, 2003; Haunschild, Schier, Marx, & Bornmann, 2018; Leydesdorff & Bornmann, 2016).

Recent classification efforts have most commonly been divided into journal-focused and paper (article)-focused solutions. The most prevalent and widely used classification of literature into disciplines is via journals, based on a simplistic assumption that a discipline can be defined through journal subject categories (Carpenter & Narin, 1973; Narin, 1976; Narin, Pinski, & Gee, 1976). Such approach is not surprising—journals often serve as anchors for individual research communities, and new journals may signify the formations of disciplines. On a more practical note, the Web of Science (WoS) Journal Citation Reports subject categories are "one of the few classification systems available, spanning all disciplines" (Rinia, van Leeuwen, Bruins, van Vuren, & Van Raan, 2001, p. 296), and is easy to implement since it is available for items in one of the most widely used bibliographic databases, WoS. WoS classifies all of the journals it indexes into approximately 250 groups called *subject categories*. Each journal is classified into one, or up to six, subject categories. The classification uses a number of heuristics and its rather general description is provided by Pudovkin and Garfield (2002). WoS classification is not explicitly hierarchical, even though some subject categories can be considered as part of other, broader ones. In addition, WoS contains categories that are explicitly broad (labeled as *multidisciplinary*) in order to describe the content of journals that publish across one broad area or across the entire field of science.

Over the years, a number of other journal-centered classifications have been developed. Most of them are hierarchical. For example Scopus, another major bibliographic database, uses All Science Journal Classification (ASJC). National Science Foundation (NSF) uses a two-level system in which journals are classified into 14 broad fields and 144 lower level fields known as *CHI*, after Narin and Carpenter's company, Computer Horizons, Inc., which developed it in the 1970s (Archambault, Beauchesne, & Caruso, 2011). Science-Metrix uses a three-level classification that classifies journals into exclusive categories using both algorithmic methods and expert judgment (Archambault et al., 2011). Glänzel and Schubert (2003) developed KU Leuven ECOOM journal classification. Gómez-Núñez, Vargas-Quesada, de Moya-Anegón, and Glänzel (2011) used reference analysis to reclassify the SCImago Journal and Country Ranks (SJR) journals into 27 areas and 308 subject categories. Some classifications used a hybrid method combining text and citations to cluster journals (Janssens, Zhang, De Moor, & Glänzel, 2009). Chen (2008) has used WoS as a starting point for developing a classification using an affinity propagation method on journal-to-journal citation network. The University of California San Diego (UCSD) classification has been developed in mapping of science efforts (Börner et al., 2012).

Journal-level classification suffers from a number of problems, many of which have been pointed out previously. For example, Klavans and Boyack (2017) found journal-based taxonomies of science to be more inaccurate than topic-based ones and therefore argued against their use. Similar findings were reported in a recent study that carried out direct comparison of journal- and article-level classifications (Shu et al., 2019) reporting that journal-level classifications have the potential to misclassify almost half of the papers. The issues with accuracy might be tied to the increase both in the number of journals that publish papers from multiple research areas and the number of papers published in those journals, making journal-level classifications problematic (Gómez et al., 1996; Wang & Waltman, 2016). Although journal-level classifications underperform compared to article-level classification in microlevel analyses, they might still be useful for (nonevaluative) macrolevel analysis (Leydesdorff & Rafols, 2009; Rafols & Leydesdorff, 2009).

The use of journals as an appropriate level for classification has been problematized even for journals with unique, nonmultidisciplinary classification in WoS, given that a journal may publish articles from different disciplines and would not be the right unit to capture interdisciplinary activities (Abramo, D'Angelo, & Zhang, 2018; Klavans & Boyack, 2010). Boyack and Klavans (2011, p. 123) suggest that "few journals are truly disciplinary." In their study of research specialties, Small and Griffith (1974) found journals to be too broad a unit of analysis and called for the use of publications instead. The mounting body of research pointing to the drawbacks of journal-based classifications has prompted the development of article-level classifications. These efforts are usually accompanied by the development of new classification schemes, and are often called *algorithmic classifications*, due to the clustering techniques used to come up with classes and categories (Ding, Ahlgren, Yang, & Yue, 2018). Klavans and Boyack (2010) have pioneered these classifications at large scale using cocitation techniques (bibliographic coupling of references and keywords) at the paper level to develop the SciTech Strategies (STS) schema consisting of 554 topics, and an alternative method based on cocitation analysis of highly cited references to identify over 84,000 paradigms. Further advances in these techniques were made by Waltman and van Eck (2012), who used direct citations with the minimum number of publications per cluster and a resolution parameter to come up with a three-level classification. Their work has been further advanced by creating a number of algorithmic classifications at different levels of granularity (Ruiz-Castillo & Waltman, 2015) and searches for the optimal resolution parameter for the level of topics (Sjögårde & Ahlgren, 2018). In addition, because these methods are based on clustering algorithms, and it has long been argued that the resulting classifications are not algorithm-neutral (Leydesdorff, 1987), some studies addressed how different algorithms affect resulting classifications (Šubelj, van Eck, & Waltman, 2016). Overall, the article-based classifications have been praised for being able to classify papers regardless of the type of journals they were published in and placing each publication into a single class/category. One of the drawbacks of the paper-level classification is the problem of naming the classes/categories (Perianes-Rodriguez & Ruiz-Castillo, 2017) making these classifications problematic for macrolevel analysis (Ding et al., 2018).

The usefulness of classification schemes for science studies and research evaluation is not determined only by its quality, but also by the availability of a classification of scientific literature at all levels of analysis (from micro to macro), flexibility for different purposes, and the simplicity of interpretation and reproduction. Although it is clear that journal-level classifications in general, and WoS journal-level classification in particular, have a number of shortcomings, they are still widely used, primarily because of their wide availability and the familiarity of audiences with WoS subject categories. An article-level classification that would still use the familiar WoS subject categories would be a welcome and practical solution to some of the problems of journal-level classification, but no such classification currently exists. The purpose of this work is to fill this gap by presenting a flexible, simple and easily reproducible method to reclassify WoS items using existing WoS categories, but at the article level. Such a classification is particularly useful for "descriptive bibliometrics" (Borgman & Furner, 2002) or "science of science" (Fortunato et al., 2018) research, especially when the comparison across all the fields and over long time periods is needed.

In addition to being journal level, there are two additional practical problems with WoS classification that will be addressed in the proposed reclassification. One problem is related to different levels of specialization of journals (Glänzel, Schubert, & Czerwon, 1999). The scope of journals ranges from highly specialized ones, via those that cover a whole range of subfields within a field or a discipline (e.g., general journals in physics or chemistry), to journals covering multiple disciplines or fields (Narin, 1976). In WoS subject categories, journals that cover entire large disciplines (broader than typical subject categories) are classified as "multidisciplinary" (e.g., "Physics, multidisciplinary" includes journals containing individual articles actually belong to specific subject categories, such as "Physics, nuclear"; "Optics"; and "Thermodynamics"). In addition, there are journals such as *Nature*, *Science* and *PNAS* that cover many disciplines and are classified in WoS as "Multidisciplinary Sciences." Such journals rarely carry truly multidisciplinary articles but rather articles from a large number of disciplines (Katz & Hicks, 1995; Waltman & van Eck, 2012). Altogether, 10% of WoS items belong to nine explicit "multidisciplinary" categories. Without the means to establish their true subject category, these articles are often excluded from the analyses of disciplinary practices, thus removing what are often articles with high impact (Fang, 2015). As a solution to this problem, a number of researchers have suggested reclassification of individual articles in such journals, especially in the subject category "Multidisciplinary Sciences." Many of the proposed solutions are based on the references of the articles (e.g., Glänzel & Schubert, 2003; Glänzel, Schubert, & Czerwon, 1999; Glänzel, Schubert, Schoepflin, & Czerwon, 1999; López-Illescas et al., 2009). A more recent solution to this problem utilized both citing and cited publications as a basis for reclassification (Ding et al., 2018). Our article-level reclassification of WoS classifies articles from such multidisciplinary journals into other more specific WoS subject categories.

The second problem of WoS classification is the lack of exclusivity (Bornmann, 2014; Herranz & Ruiz-Castillo, 2012a, b). Namely, many journals in WoS (containing, by our estimate, 40% of all items in WoS) are assigned more than one subject category (in agreement with other studies, such as Herranz and Ruiz-Castillo (2012a), who reported that 42% of 3.6 million articles published in 1998–2002 were assigned to more than one category, and Wang and Waltman (2016), who reported that almost 60% of journals in WoS are assigned a single category). Multiple subject categories lead to ambiguities when it comes to the analysis. Should such articles be counted in each category, artificially increasing their weight in the overall analysis? Should they be counted fractionally, thus decreasing their weight within a single category? How to treat them when a nonoverlapping delineation is desired, as is often the case? Most journals are assigned multiple categories because they cover more than one subject, even though articles in them usually deal predominantly with one subject. Less often the articles, and not just the journal, are indeed positioned at the intersection of several subjects, and multiple subjects may be appropriate. In such cases we may still wish to assign a primary single category to arrive at nonoverlapping delineation of scientific literature. As in the case of "multidisciplinary" categories, references have been proposed for the classification of journals (and articles) with multiple WoS categories into unique categories (e.g., Glänzel & Schubert, 2003; Glänzel, Schubert, & Czerwon, 1999; Narin, 1976; Narin et al., 1976). Our article-level reclassification will assign the most prevalent subject category as the single category for each article and remove the ambiguity. Information regarding potential multidisciplinarity at the level of article will nevertheless be retained if required for the analysis.

Finally, many of the large-scale studies, especially those that are comparative in nature, require a smaller number of broader classes. To achieve this goal, we additionally categorize articles into 14 broad areas, based on NSF WebCASPAR classification (Javitz et al., 2010).

2. PROPOSED APPROACH

In this paper we propose a *reference*-based (re)classification system that can easily be applied at various levels of granularity. The approach is relatively straightforward and allows for easy reproducibility. Also, by using existing WoS subject categories as units of classification, the approach obviates the need to develop an independent scheme for defining and naming of the classes/categories.

Following previous efforts, our approach is to use each item's references to infer the topic of a bibliographic item. However, given the problems identified above, we initially use only references that were published in journals that have a single subject category that is not "multidisciplinary" (i.e., it is not published in multidisciplinary or general disciplinary journals). Such an approach appears appropriate given that previous studies have found WoS subject categories to be fairly precise description of subjects of individual articles published in journals described with one or two subject categories (Glänzel, Schubert, & Czerwon, 1999; Glänzel et al., 1999) and that central journals within particular disciplines "exhibit little cross citing" (Narin, 1976, p. 194). For the purposes of this paper, we refer to such items as *classifier references* or *classifiers*. The tallying of the subject categories of classifier references allows us to determine the unique WoS subject category of items that originally had multiple categories or were placed in multidisciplinary categories. However, what is novel in our approach is that the method is applied to reclassify all items that contain classifier references, whether they had unique original (journal-based) classification or not, in order to obtain a consistent comprehensive classification at the level of *individual* items (i.e., articles). Also, unlike a number of other approaches, this one does not apply a particular threshold that an item should meet in order to be classified into a particular category (e.g., Fang, 2015; Glänzel, Schubert, & Czerwon, 1999; Gómez-Núñez et al., 2011; López-Illescas et al., 2009), giving every item a definitive category.

The proposed approach allows both for the classification into exclusive classes (where each article is placed into a single class) and, if needed for particular research questions, a construction of a detailed vector description of disciplinary composition of articles (and consequently, of journals, authors, etc.), which will be described in a future work.

In the remainder of the paper we describe the data, methodology and evaluation of the proposed approach using WoS. The approach itself is rather general and a similar methodology can be used both to reclassify articles in WoS using a different starting classification of core journals or classifying articles in other databases that use journal-level classifications. We present the results of the classification of individual items both at the level of subject categories and an aggregated level of broad research areas. New classifications are evaluated using an automated method and validated using blind manual classification.

3. DATA AND METHODOLOGY

3.1. Initial Reclassification

For (re)classification we use the full WoS Core Collection database, containing items published from 1900 through the end of 2017. The database contains 69 million items (bibliographic entries), of which 55 million have at least one reference recorded in the database. WoS items belong to different document types: articles, proceedings papers, editorials, letters, reviews, etc. We perform the classification on (and using) all document types but carry out the evaluation and validation on document types *article* and *proceedings paper*—the items containing original research and most often used in analyses. There are 45 million items of these two types in WoS with at least one reference, and we refer to them collectively as just the "articles." The edition of WoS used in this work uses 252 subject categories. Classification was extracted from the SQL table `subjects` using the subject category collection referred to by field `ascatype` as the "traditional" classification. Categories are listed in Table A.1 in the Appendix.

For higher level classification, we place each of 252 subject categories into 14 broad areas. Names of broad areas are taken from NSF WebCASPAR Broad Field (Javitz et al., 2010), except that we include their "Other life sciences" within "Medical sciences." Mapping between WoS subject categories and our broad areas, given in Table A.1, follows Javitz et al. (2010) mapping between the ipIQ Fine Field category (formerly CHI category) and WebCASPAR Broad Field whenever there is an ipIQ category that clearly matches WoS category. In other instances (half of all WoS categories) the broad category is determined by the author.

WoS attempts to match each item's references to other items in WoS. It is the items that have matched references that can be reclassified using the proposed method. Furthermore, to allow initial classification using our method, the references need to be *classifiers* (i.e., items whose original classification is unique and not multidisciplinary). Forty-one million items contain classifier references and can therefore be classified into subject categories, of which 36 million are articles, representing 79% of all articles with references. We will outline later in this section how this percentage can be further increased using an iterative approach. Classification into broader areas is possible for a larger number of items (44 million of any type, and 38 million articles), because classifiers can include items classified as multidisciplinary as long as they can be placed in some broad area (e.g., category "Physics, multidisciplinary" can be used, but "Multidisciplinary Sciences" cannot). The fraction of articles (containing references) that can be classified, as a function of publication year, is shown in Figure 1. The fractions are above 90% in recent years and are relatively high since the 1950s. The rising trend is likely a combination of several factors: more complete efforts on behalf of database administrators to match the references in recent publications, journal articles becoming "the central medium for the dissemination and exchange of scientific ideas" (Bowker, 2005, p. 126), and the overall increase in the number of references per paper over time (Milojević, 2012; Price, 1963; van Raan, 2000), all of which increase the chances of an article containing classifier references. The items that remain without new classification are rarely full-fledged research papers but most often items such as book reviews or short conference proceedings.

For classification at the subject category level, 20 million items serve as classifiers. An algorithm for the entire classification procedure is given in Figure 2. Classification at the level of subject categories proceeds as follows. For each classifiable item we go through all of its classifier references and produce a ranked list of their subject categories. A subject category that is

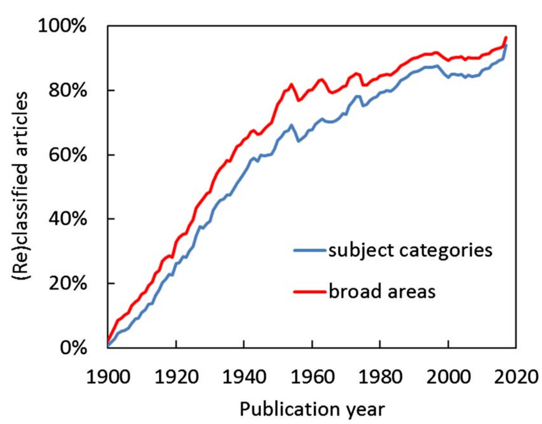

Figure 1. Percentage of all articles containing references that can be reclassified into subject categories or broad areas as a function of article publication year. Numbers are based on initial reclassification. An iterative pass will increase the percentage of articles classified into subject categories by 5%.

```
LOAD DATA: All WoS items
       WOS_ID # WoS identifier
       CLASS         # Classification*
*      = Original WoS subject categories (one or more)    OR
       = Original WoS subject categories converted into one or more broad areas

[ Optional, for iterative (second) pass
[LOAD DATA: All reclassified WoS items
[      WOS_ID # WoS identifier
[      NEW_CLASS     # Classification obtained in first pass of this algorithm

LOAD DATA: References of all WoS items
       WOS_ID # Citing WoS identifier
       CWOS_ID# WoS identifier of cited item

[      IF NEW_CLASS(CWOS_ID) exists
[             CLASS(CWOS_ID) = NEW_CLASS(CWOS_ID) # Replace with new classification
       IF CLASS(CWOS_ID) exists AND unique AND NOT multidisciplinary # Classifier reference
              DIST(WOS_ID)+=1 # Increment distribution of categories/areas for a given WoS
item
              COUNT(CLASS)+=1 # Increment counter for this category/area

LOOP: All WoS items with classifier references
       SORT DESCENDING DIST(WOS_ID) # Determine 1st and 2nd  most frequent category/area
(CLASS1/CLASS2)
       IF N(CLASS1) = N(CLASS2)  # Tie
              LOOP: CLASS(WOS_ID) # Original categories for the item
                     DIST(WOS_ID)+=1  # Add them to distribution
              SORT DESCENDING DIST(WOS_ID) # Redetermine most frequent category
                     IF N(CLASS1) = N(CLASS2)  # Still a tie
                            SORT DESCENDNG COUNT(CLASS1,CLASS2) # Take bigger class as the
final class
       NEW_CLASS(WOS_ID) = CLASS1
       OUTPUT NEW_CLASS(WOS_ID)
```

Figure 2. An algorithm (pseudocode) describing the reclassification procedure.

the most frequent is adopted as a new (reclassified) subject category. Most often the distribution of categories is dominated by the most frequent subject category (the article is predominantly unidisciplinary). Occasionally, the tallying results in a tie between two most frequent categories (13% of cases). We attempt to break the ties by adding to the tally the original subject category (or categories, if they were multiple). This can be done if the original subject category is nonmultidisciplinary. In this way, 52% of the ties can be broken. Otherwise, we adopt as the final classification the category with a larger number of articles.

The granularity of reclassified subject categories defined as the number of items divided by the sum of the items in each category squared (Waltman, Boyack, Colavizza, & Van Eck, 2019) is 1.5×10^{-6}, compared to 2.3×10^{-6} for the original classification (i.e., it is relatively similar). The number of categories of different sizes (i.e., total number of reclassified items) is presented in Figure 3. Categories span a wide range of sizes.

Classification at the level of broad areas proceeds in the same way, except that the ranked list is made of classifiers' broad areas. For classification into broad areas, the number of classifiers is 50% larger than in the case of subject categories (30 million), because individual subject categories of items that have multiple subject categories most often belong to the same broad area, and such items are therefore eligible to serve as classifiers. For the classification of items into broad areas, ties happen in 4% of all cases, and can be resolved by including the

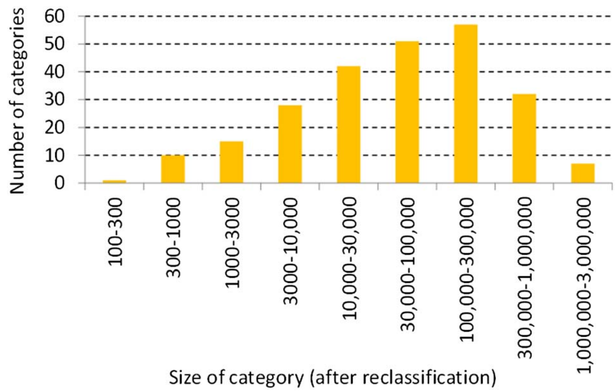

Figure 3. Size distribution of WoS subject categories after initial reclassification.

original broad area in the ranked list in 69% of those cases. Otherwise, we take the more populous category as the final one.

Overall, the classification is not sensitive to the extent of the classifier set. We perform the test in which we base the classification on only half of all available classifiers. The resulting broad categories agree with the ones obtained with the full classifier set in 94% of cases.

The exact counts pertaining to the data set and initial reclassification are provided in Tables 1 and 2.

3.2. Iterative Reclassification

Once the reclassification has been carried out, it is possible and often recommended to carry out the process of reclassification iteratively. In iterative reclassification, the tallying of subject categories of references and the determination of which reference can serve as classifier is based on the reclassified subject categories (or broad areas, for the high-level classification). The process can be repeated multiple times, but here we limit ourselves to one iterative pass and the quality and extensiveness of this second reclassification compared to the first. The iterative pass is procedurally similar to the original one, and the needed modifications are laid out in Figure 2. After the iterative pass 9% of items acquire a different broad-area classification, and 20% of items acquire a different subject category.

There are two principal reasons for carrying out the iterative pass: an increase in the number of items that can be classified, and, potentially, an increased accuracy of new categories. In the original pass only items that had classifier references could be classified, which, as we have shown, represents 79% of all articles, and around 90% of recent articles. Items that have only had references with multiple original categories and/or multidisciplinary categories could

Table 1. Number of items from the Web of Science used in (re)classification

	All types	Articles + conference proceedings
All items	69,326,147	49,775,351
with references	54,581,163	45,219,572
multidisciplinary	5,585,211	4,640,854
multidisciplinary science	1,317,033	1,071,437

Table 2. Number of classified items of different types after initial reclassification. Percentage in parentheses is with respect to all such items with references

	Subject category classification		**Broad area classification**	
	All types	Articles + conference proceedings	All types	Articles + conference proceedings
Classifier items	20,286,801		29,853,395	
Classified items	41,132,197 (75%)	35,940,588 (79%)	43,847,374 (80%)	38,118,382 (84%)
multidisciplinary	3,719,208 (67%)	2,599,373 (56%)		
multidisciplinary science	896,169 (68%)	740,592 (69%)	909,543 (69%)	792,875 (74%)

not be classified. However, after the first reclassification, most of these references will receive a unique, nonmultidisciplinary classification and can now serve as classifiers. The numbers of items and articles that can be classified in the iterative pass are presented in Table 3. Comparing these numbers to those in Table 2 we see a relatively significant increase in the number of items or articles that get classified into subject categories (~8%) and a more modest increase of items/articles classified into broad areas (~2%).

The increase of completeness using the iterative pass is especially significant in the cases where the majority of the journals in some discipline originally had multiple WoS categories and were therefore precluded from serving as classifier references. Although such cases are not common in general, one of them happens to include core journals in quantitative studies of science. Specifically, *Journal of Informetrics* (JoI), *Scientometrics*, and *Journal of the Association for Information Science and Technology* (JASIST) are all listed with two WoS subject categories: “Computer Science, Interdisciplinary Applications” and “Information Science & Library Science,” which means that they cannot serve as classifiers, at least not in the initial pass. For example, out of 840 items published in JoI, 663 can be classified in the first pass (79%), a lower fraction than on average. Interestingly, of the classified items, 41% received the classification of “Information Science & Library Science,” whereas essentially none were classified as “Computer Science, Interdisciplinary Applications.” This shows that the reclassification successfully rejected this obviously inappropriate categorization. In the iterative pass, however, the number of classified articles increased substantially, to 796 (95% of total). Furthermore, 52% have now received the classification of “Information Science & Library Science,” the most of any category. Other frequent categories included “Economics” (9%), “History and Philosophy of Science” (8%), and “Sociology” (6%).

Table 3. Number of classified items of different types after the second (iterative) reclassification

	Subject category classification		**Broad area classification**	
	All types	Articles + conference proceedings	All types	Articles + conference proceedings
Classifier items	36,104,403		38,504,614	
Classified items	44,349,678 (81%)	38,450,585 (85%)	44,936,331 (80%)	38,918,386 (84%)
multidisciplinary	4,317,080 (77%)	2,931,707 (63%)		
multidisciplinary science	1,011,770 (77%)	804,203 (75%)	968,783 (74%)	822,849 (77%)

To conclude, extending the classification to include the iterative pass provides an increase in the number of classified items (especially at subject category level), which for certain cases can be quite significant.

4. VALIDATION AND EVALUATION

The validation and evaluation of the approach and of the final reclassification is performed using three tests, each serving a separate purpose:

1. Automatic internal test against the original WoS classification, in order to validate the methodology.
2. Manual tests in order to evaluate the accuracy of reclassification in comparison to the original WoS classification.
3. Manual external test in order to evaluate the overall reliability of the resulting classification.

4.1. Validation

To validate the methodology and hone the approach, we have performed an automatic test by calculating the percentage of articles whose original and new classifications agree. This test can only be performed on items whose original classification was unique and nonmultidisciplinary. This test is internal, because we do not evaluate the accuracy of the original WoS classification using any external knowledge. We do not expect the test to produce 100% agreement. First of all, the reclassification is at the level of articles, whose topics may be to some extent different from those of their journals, and second, because the subject categories are rarely entirely mutually exclusive, so a reclassified category may be related but not exactly the same as the original one. The value of this test is in the relative assessment. When evaluating, for example, two article-level classification schemes, the one that has a higher level of agreement with respect to, however imperfect, reference classification (in this case the original classification), should be considered more accurate internally. For the reclassification at the level of subject categories we find the overall agreement to be 66% after the initial reclassification and 58% after the iterative pass. In comparison, an alternative classification scheme that we devised but ultimately did not adopt, which uses the similarity of titles to perform reclassification, had an agreement of <50%. For this alternative method we calculated TF-IDF ("term frequency-inverse document frequency") values between each article title to be reclassified and each of the classifier articles (articles that have a unique nonmultidisciplinary WoS category). In this case, IDF actually represents inverse title word frequency, which was first determined from the entire data set, and TF-IDF is the sum of all IDFs of the words that overlap. For an article to be classified we adopt the category of an article with the greatest TF-IDF value.

The level of agreement varies from one subject category to another. It is highest for astronomy and astrophysics—97%. The number of articles in different categories varies widely, with the largest category being 2,000 times larger than the smallest (see Figure 3). We find that the agreement is correlated with the size of the subject category, with larger categories having a higher level of agreement. This is probably because some of the smaller categories can also be considered subcategories of larger ones, so many of the articles get reclassified into these larger categories. The opposite (an item that was originally in a larger category being reclassified into a smaller one) is less likely simply because there are fewer classifiers that belong to smaller categories. Furthermore, small categories may represent more recent disciplines, which would naturally cite works from the disciplines from which they emerged. As we will see shortly, this lower level of agreement for smaller categories does not imply that the new category is incorrect—it may simply be placing individual items in a related, equally correct, subject category or may reflect a high degree of interdisciplinarity of an article.

We perform a similar automatic validation for broad-area classification and find the overall agreement of 85% after the initial reclassification and 82% after the iterative pass. Agreement in different areas is now more similar, ranging from 60% for agricultural sciences (which tends to be highly interdisciplinary) to 93% for astronomy and astrophysics (which has a low degree of interdisciplinarity), and the level of agreement is not correlated with the size of the area.

4.2. Manual Evaluation of Accuracy

The internal validation in itself does not allow us to evaluate the *quality* of the reclassification with respect to the original classification. We assess this by manual evaluation, performed by the author, in the following way. For 142 randomly selected articles whose original classification was unique and non-multidisciplinary, we output the original and new subject categories. The order in which the two categories are written out is randomly reversed in 50% of cases. The evaluator does not know a priori which category is original and which is new—this information is saved separately and is used only after the evaluation was performed. The evaluator's task is to select the subject category that better describes the article based on its title (and abstract, if necessary), but ignoring the name of the journal, so as not to bias the assessment, because the journal topic was the basis for the original classification. If both categories are estimated to be equally appropriate, this is also indicated. After the initial reclassification, 91 out of 142 articles had the same new and old category (64%; in agreement with the full sample). For 25 articles, the old and new categories were equally good (most often because one category can be considered a part of another). Of the remaining 26 articles, the original classification was considered better in 15 cases and the new one in 11 cases. In 15 cases where the original classification was considered better, the new one was still essentially correct in 13 cases. Altogether, the initial reclassification is nearly as good as the original one (i.e., we have not introduced spurious results in the process of reclassification). The differences between the original and new classifications revealed by automated validation can be attributed to articles' interdisciplinarity (such that both categories are correct) and to somewhat stratified, nonexclusive nature of WoS subject categories (again making both categories correct).

Manual evaluation is also carried out for the same 142 articles for their broad-area classifications. The areas agree for 124 articles (87%; in agreement with the full sample) and are considered equally good in four cases. Of the remaining 14 articles, the original classification is considered better in only three cases, and the new area is considered more accurate in the remaining 11 cases (i.e., the new classification is overall somewhat better).

4.3. Manual Evaluation of Reliability

The overall reliability of the new classification is what is ultimately of most interest. We test it based on an external assessment, which looks at all items irrespective of how the items were originally classified (i.e., it includes items that originally had ambiguous classification or where the classification was effectively missing because the item was published in a multidisciplinary journal). The test is performed by the author by evaluating the correctness of subject categories and broad areas of 100 randomly selected items, based on their titles and abstracts. We find 92% of subject categories and 95% of broad areas to be correct after the initial reclassification. The accuracy increased to 95% for subject categories and 97% for broad areas after the iterative pass. It needs to be pointed out that whereas the error rate is relatively small across the entire data set, it need not be uniform in different disciplines or for different journals, so it is advisable to perform similar manual tests for subsets of a data set that one wishes to study.

5. EXTENSION OF THE METHOD USING CITATION DATA

It is in principle possible to adapt our method to use not only the references as the basis for reclassification but also the citations. Citations, at least in the initial reclassification, would also have to come from sources that have a unique, nonmultidisciplinary WoS category. The use of citations may allow some items to be classified that otherwise did not have classifier references. We carry out such reclassification at broad-area level and find that the number of classified items increases from 43,847,374 (63% of all possible items, regardless of whether they had references or not) to 47,593,363 (69%). The increase exceeds that from the iterative pass (44,936,331 or 65%). The fraction is still short of 100% because most of the items that lack references also lack citations (most of them are not really citable items.) One possible drawback of using citations is the disproportionality of information available for different items. Unlike references, the number of which tends to be normally distributed, the citations follow a power law distributions, with most articles having few citations and few having thousands. Furthermore, citations constantly change, making the proposed procedure essentially non reproducible.

There are 6% of articles with no linked references or citations. These are mostly items more than half a century old. For these items, one could apply the TF-IDF method that we discussed in Section 4, which has 100% completeness.

6. DISCUSSION AND CONCLUSION

This paper proposes a method of classification that is based on references and applies it to classifying WoS articles, both at the field and broad research area levels. Although some of the proposed clustering-based methods may lead to a better delineation, especially for citation normalization, the proposed method has a number of advantages: It is easily replicated and utilizes widely used WoS subject categories and NSF broad subject areas, does not require extensive computational resources (~40 million articles can be classified on a personal computer within several hours), and avoids the problem of naming classes/categories (something that article-level classifications have struggled with but are making progress on due to more sophisticated natural language processing approaches and including a wider range of fields of bibliographic records). The major purpose for this classification is devising a flexible and simple way of classifying all of the WoS literature for the purposes of "descriptive bibliometrics" or "science of science" studies. The classification has not been designed for the purposes of research evaluation, and if used in that context, may be outperformed by approaches that identify more focused comparison sets, as in Colliander and Ahlgren (2019), for example.

The major limitations of the proposed method are tied to its usage of WoS subject categories as a starting point and references as a major source of data. Because it uses WoS subject categories as seeds, the proposed classification will inherit some of the known problems of this classification, primarily having to do with erroneous lumping of unconnected journals into a single category. This limitation can potentially be alleviated by the iterative procedure. Furthermore, because the method is based on references, it can be applied only to the items that have references. This should not be a problem with most contemporary original research but may prove problematic for other types of contributions and for older items. At the same time, relying on references rather than citations, as in some other studies, has some advantages, since more articles have cited other works than are cited themselves. This should lead to a higher recall than citation-based classifications have. An approach that combines references and citations is also possible and was described.

Overall, we find the error rate of the resulting classification to be relatively low (<5%) making it a reasonably reliable basis for a wide range of studies. However, the accuracy may be higher or lower for specific research areas, so, as with any classification, users should exercise caution and validate the classification for the sample of interest. Also, as we have pointed out, especially at the level of 252 subject categories, it is often the case that more than one category is essentially correct, so it is advisable to consider all potentially relevant categories when the recall of a sample is important. This is less of an issue for broad areas.

ACKNOWLEDGMENTS

This work uses Web of Science data by Clarivate Analytics provided by the Indiana University Network Science Institute and the Cyberinfrastructure for Network Science Center at Indiana University.

AUTHOR CONTRIBUTIONS

Staša Milojević: conceptualization, data curation, formal analysis, methodology, writing.

COMPETING INTERESTS

No competing interests to declare.

FUNDING INFORMATION

This material is partially based upon work supported by the Air Force Office of Scientific Research under award number FA9550-19-1-0391.

DATA AVAILABILITY

The data used in this paper is proprietary and cannot be posted in a repository.

REFERENCES

Abramo, G., D'Angelo, C. A., & Zhang, L. (2018). A comparison of two approaches for measuring interdisciplinary research output: The disciplinary diversity of authors vs the disciplinary diversity of the reference list. *Journal of Informetrics*, *12*(4), 1182–1193.

Archambault, É., Beauchesne, O. H., & Caruso, J. (2011). Towards a multilingual, comprehensive and open scientific journal ontology. Paper presented at the *Proceedings of the 13th International Conference of the International Society for Scientometrics and Informetrics*, South Africa: Durban.

Borgman, C. L., & Furner, J. (2002). Scholarly communication and bibliometrics. In B. Cronin (Ed.), *Annual Review of Information Science and Technology* (Vol. *36*, pp. 3–72). Medford, NJ: Information Today.

Börner, K., Klavans, R., Patek, M., Zoss, A. M., Biberstine, J. R., Light, R. P., …, Boyack, K. W. (2012). Design and update of a classification system: The UCSD map of science. *PLOS One*, *7*(7), e39464.

Bornmann, L. (2014). Assigning publications to multiple subject categories for bibliometric analysis: An empirical case study based on percentiles. *Journal of Documentation*, *70*(1), 52–61.

Bowker, G. C. (2005). *Memory practices in the sciences*. Cambridge, MA: MIT Press.

Boyack, K. W., & Klavans, R. (2011). Multiple dimensions of journal specificity: Why journals can't be assigned to disciplines. Paper presented at The 13th Conference of the International Society for Scientometrics and Informetrics, Durban, South Africa.

Bryant, R. (2000). *Discovery and decision: Exploring the metaphysics and epistemology of scientific classification*. London: Associated University Presses.

Carpenter, M. P., & Narin, F. (1973). Clustering of scientific journals. *Journal of the American Society for Information Science*, *24*(6), 425–436.

Chen, C. M. (2008). Classification of scientific networks using aggregated journal-journal citation relations in the Journal Citation Reports. *Journal of the American Society for Information Science and Technology*, *59*(14), 2296–2304.

Colliander, C., & Ahlgren, P. (2019). Comparison of publication level approaches to ex post citation normalization. *Scientometrics*, *120*(1), 283–300.

Ding, J., Ahlgren, P., Yang, L., & Yue, T. (2018). Disciplinary structures in *Nature*, *Science* and *PNAS*: Journal and country levels. *Scientometrics*, *116*(3), 1817–1852.

Dolby, R. G. A. (1979). Classification of the sciences: The nineteenth century tradition. In R. F. Ellen & D. Reason (Eds.), *Classifications in Their Social Context* (pp. 167–193). London: Academic Press.

Durkheim, E., & Mauss, M. (1963). *Primitive classification*. Chicago: University of Chicago Press.

Fang, H. (2015). Classifying research articles in multidisciplinary science journals into subject categories. *Knowledge Organization*, *42*(3), 139–153.

Fortunato, S., Bergstrom, C. T., Börner, K., Evans, J. A., Helbing, D., Milojević, S., …, Barabási, A.-L. (2018). Science of science. *Science*, *359*(6379), eaao0185.

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

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

Glänzel, W., Schubert, A., Schoepflin, U., & Czerwon, H. J. (1999). An item-by-item subject classification of papers published in journals covered by the SSCI database using reference analysis. *Scientometrics*, *46*(3), 431–441.

Gläser, J., Glänzel, W., & Scharnhorst, A. (2017). Same data—different results? Towards a comparative approach to the identification of thematic structures in science. *Scientometrics*, *111*(2), 981–998.

Gómez-Núñez, A. J., Vargas-Quesada, B., de Moya-Anegón, F., & Glänzel, W. (2011). Improving SCImago Journal & Country Rank (SJR) subject classification through reference analysis. *Scientometrics*, *89*(3), 741–758.

Gómez, I., Bordons, M., Fernandez, M., & Méndez, A. (1996). Coping with the problem of subject classification diversity. *Scientometrics*, *35*(2), 223–235.

Haunschild, R., Schier, H., Marx, W., & Bornmann, L. (2018). Algorithmically generated subject categories based on citation relations: An empirical micro study using papers on overall water splitting. *Journal of Informetrics*, *12*(2), 436–447.

Herranz, N., & Ruiz-Castillo, J. (2012a). Multiplicative and fractional strategies when journals are assigned to several subfields. *Journal of the American Society for Information Science and Technology*, *63*(11), 2195–2205.

Herranz, N., & Ruiz-Castillo, J. (2012b). Sub-field normalization in the multiplicative case: High- and low-impact citation indicators. *Research Evaluation*, *21*(2), 113–125.

Janssens, F., Zhang, L., De Moor, B., & Glänzel, W. (2009). Hybrid clustering for validation and improvement of subject-classification schemes. *Information Processing & Management*, *45*(6), 683–702.

Javitz, H., Grimes, T., Hill, D., Rapoport, A., Bell, R., Fecso, R., & Lehming, R. (2010). U.S. Academic Scientific Publishing. Working paper SRS 11-201. Arlington, VA: National Science Foundation, Division of Science Resources Statistics.

Katz, J. S., & Hicks, D. (1995). The classification of interdisciplinary journals: A new approach. Paper presented at the *Proceedings of the Fifth International Conference of the International Society for Scientometrics and Informetrics*, Rosary College, River Forest, IL.

Klavans, R., & Boyack, K. W. (2010). Toward an objective, reliable and accurate method for measuring research leadership. *Scientometrics*, *82*(3), 539–553.

Klavans, R., & Boyack, K. W. (2017). Which type of citation analysis generates the most accurate taxonomy of scientific and technical knowledge? *Journal of the Association for Information Science and Technology*, *68*(4), 984–998.

Leydesdorff, L. (1987). Various methods for the mapping of science. *Scientometrics*, *11*(5–6), 295–324.

Leydesdorff, L., & Bornmann, L. (2016). The operationalization of "fields" as WoS subject categories (WCs) 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., & Rafols, I. (2009). A global map of science based on the ISI subject categories. *Journal of the American Society for Information Science and Technology*, *60*(2), 348–362.

López-Illescas, C., Noyons, E. C., Visser, M. S., De Moya-Anegón, F., & Moed, H. F. (2009). Expansion of scientific journal categories using reference analysis: How can it be done and does it make a difference? *Scientometrics*, *79*(3), 473–490.

Milojević, S. (2012). How are academic age, productivity and collaboration related to citing behavior of researchers? *PLOS One*, *7*(11), e49176.

Narin, F. (1976). *Evaluative bibliometrics: The use of publication and citation analysis in the evaluation of scientific activity*. Cherry Hill, NJ: Computer Horizons.

Narin, F., Carpenter, M., & Berlt, N. C. (1972). Interrelationships of scientific journals. *Journal of the American Society for Information Science*, *23*(5), 323–331.

Narin, F., Pinski, G., & Gee, H. H. (1976). Structure of the biomedical literature. *Journal of the American Society for Information Science*, *27*(1), 25–45.

Perianes-Rodriguez, A., & 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.

Price, D. J. d. S. (1963). *Little science, big science*. New York: Columbia University Press.

Pudovkin, A. I., & Garfield, E. (2002). Algorithmic procedure for finding semantically related journals. *Journal of the American Society for Information Science and Technology*, *53*(13), 1113–1119.

Rafols, I., & Leydesdorff, L. (2009). Content-based and algorithmic classifications of journals: Perspectives on the dynamics of scientific communication and indexer effects. *Journal of the American Society for Information Science and Technology*, *60*(9), 1823–1835.

Rinia, E. J., van Leeuwen, T. N., Bruins, E. E. W., van Vuren, H. G., & Van Raan, A. F. J. (2001). Citation delay in interdisciplinary knowledge exchange. *Scientometrics*, *51*(1), 293–309.

Ruiz-Castillo, J., & Waltman, L. (2015). Field-normalized citation impact indicators using algorithmically constructed classification systmes of science. *Journal of Informetrics*, *9*(1), 102–117.

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

Sjögårde, P., & Ahlgren, P. (2018). Granularity of algorithmically constructed publication-level classifications of research publications: Identification of topics. *Journal of Informetrics*, *12*(1), 133–152.

Small, H., & Griffith, B. C. (1974). The structure of scientific literatures I: Identifying and graphing specialties. *Science Studies*, *4*(1), 17–40.

Small, H., & Koenig, M. E. D. (1977). Journal clustering using a bibliographic coupling method. *Information Processing & Management*, *13*(5), 277–288.

Šubelj, L., van Eck, N. J., & Waltman, L. (2016). Clustering scientific publications based on citation relations: A systematic comparison of different methods. *PLOS One*, *11*(4), e0154404.

van Raan, A. F. J. (2000). On growth, ageing, and fractal differentiation of science. *Scientometrics*, *47*(2), 347–362.

Waltman, L., Boyack, K. W., Colavizza, G., & Van Eck, N. J. (2019). A principled methodology for comparing relatedness measures for clustering publications. arXiv:1901.06815.

Waltman, L., & van Eck, N. J. (2012). A new methodology for constructing a publication-level classification system of science. *Journal of the American Society for Information Science and Technology*, *63*(12), 2378–2392.

Wang, Q., & 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.

Zitt, M. (2015). Meso-level retrieval: IR-bibliometrics interplay and hybrid citation-words methods in scientific fields delineation. *Scientometrics*, *102*(3), 2223–2245.

APPENDIX

Table A1. The list of WoS subject categories and corresponding broad areas

WoS subject category	Broad area
Agriculture, Dairy & Animal Science	Agricultural sciences
Agriculture, Multidisciplinary	Agricultural sciences
Agronomy	Agricultural sciences
Fisheries	Agricultural sciences
Food Science & Technology	Agricultural sciences
Forestry	Agricultural sciences
Green & Sustainable Science & Technology	Agricultural sciences
Horticulture	Agricultural sciences
Astronomy & Astrophysics	Astronomy
Anatomy & Morphology	Biological sciences
Biochemical Research Methods	Biological sciences
Biochemistry & Molecular Biology	Biological sciences
Biodiversity Conservation	Biological sciences
Biology	Biological sciences
Biophysics	Biological sciences
Biotechnology & Applied Microbiology	Biological sciences
Cell & Tissue Engineering	Biological sciences
Cell Biology	Biological sciences
Developmental Biology	Biological sciences
Ecology	Biological sciences
Entomology	Biological sciences
Evolutionary Biology	Biological sciences
Genetics & Heredity	Biological sciences
Microbiology	Biological sciences
Mycology	Biological sciences
Nutrition & Dietetics	Biological sciences
Ornithology	Biological sciences
Paleontology	Biological sciences
Parasitology	Biological sciences
Physiology	Biological sciences

Table A1. (*continued*)

WoS subject category	Broad area
Plant Sciences	Biological sciences
Reproductive Biology	Biological sciences
Virology	Biological sciences
Zoology	Biological sciences
Chemistry, Analytical	Chemistry
Chemistry, Applied	Chemistry
Chemistry, Inorganic & Nuclear	Chemistry
Chemistry, Medicinal	Chemistry
Chemistry, Multidisciplinary	Chemistry
Chemistry, Organic	Chemistry
Chemistry, Physical	Chemistry
Crystallography	Chemistry
Electrochemistry	Chemistry
Polymer Science	Chemistry
Spectroscopy	Chemistry
Computer Science, Artificial Intelligence	Computer sciences
Computer Science, Cybernetics	Computer sciences
Computer Science, Hardware & Architecture	Computer sciences
Computer Science, Information Systems	Computer sciences
Computer Science, Interdisciplinary Applications	Computer sciences
Computer Science, Software Engineering	Computer sciences
Computer Science, Theory & Methods	Computer sciences
Medical Informatics	Computer sciences
Agricultural Engineering	Engineering
Automation & Control Systems	Engineering
Construction & Building Technology	Engineering
Energy & Fuels	Engineering
Engineering, Aerospace	Engineering
Engineering, Biomedical	Engineering
Engineering, Chemical	Engineering
Engineering, Civil	Engineering

Table A1. (*continued*)

WoS subject category	Broad area
Engineering, Electrical & Electronic	Engineering
Engineering, Environmental	Engineering
Engineering, Geological	Engineering
Engineering, Industrial	Engineering
Engineering, Manufacturing	Engineering
Engineering, Marine	Engineering
Engineering, Mechanical	Engineering
Engineering, Multidisciplinary	Engineering
Engineering, Ocean	Engineering
Engineering, Petroleum	Engineering
Imaging Science & Photographic Technology	Engineering
Instruments & Instrumentation	Engineering
Materials Science, Biomaterials	Engineering
Materials Science, Ceramics	Engineering
Materials Science, Characterization & Testing	Engineering
Materials Science, Coatings & Films	Engineering
Materials Science, Composites	Engineering
Materials Science, Multidisciplinary	Engineering
Materials Science, Paper & Wood	Engineering
Materials Science, Textiles	Engineering
Mathematical & Computational Biology	Engineering
Medical Laboratory Technology	Engineering
Metallurgy & Metallurgical Engineering	Engineering
Mining & Mineral Processing	Engineering
Nanoscience & Nanotechnology	Engineering
Neuroimaging	Engineering
Nuclear Science & Technology	Engineering
Operations Research & Management Science	Engineering
Remote Sensing	Engineering
Robotics	Engineering
Telecommunications	Engineering

Table A1. (*continued*)

WoS subject category	Broad area
Transportation	Engineering
Transportation Science & Technology	Engineering
Environmental Sciences	Geosciences
Environmental Studies	Geosciences
Geochemistry & Geophysics	Geosciences
Geography, Physical	Geosciences
Geology	Geosciences
Geosciences, Multidisciplinary	Geosciences
Limnology	Geosciences
Marine & Freshwater Biology	Geosciences
Meteorology & Atmospheric Sciences	Geosciences
Mineralogy	Geosciences
Oceanography	Geosciences
Soil Science	Geosciences
Water Resources	Geosciences
Archaeology	Humanities
Architecture	Humanities
Art	Humanities
Asian Studies	Humanities
Classics	Humanities
Cultural Studies	Humanities
Dance	Humanities
Ethics	Humanities
Ethnic Studies	Humanities
Film, Radio, Television	Humanities
Folklore	Humanities
History	Humanities
History & Philosophy Of Science	Humanities
History Of Social Sciences	Humanities
Humanities, Multidisciplinary	Humanities
Language & Linguistics	Humanities

Table A1. (*continued*)

WoS subject category	Broad area
Literary Reviews	Humanities
Literary Theory & Criticism	Humanities
Literature	Humanities
Literature, African, Australian, Canadian	Humanities
Literature, American	Humanities
Literature, British Isles	Humanities
Literature, German, Dutch, Scandinavian	Humanities
Literature, Romance	Humanities
Literature, Slavic	Humanities
Logic	Humanities
Medical Ethics	Humanities
Medieval & Renaissance Studies	Humanities
Music	Humanities
Philosophy	Humanities
Poetry	Humanities
Religion	Humanities
Theater	Humanities
Women's Studies	Humanities
Mathematics	Mathematical sciences
Mathematics, Applied	Mathematical sciences
Mathematics, Interdisciplinary Applications	Mathematical sciences
Statistics & Probability	Mathematical sciences
Allergy	Medical sciences
Andrology	Medical sciences
Anesthesiology	Medical sciences
Audiology & Speech-Language Pathology	Medical sciences
Cardiac & Cardiovascular Systems	Medical sciences
Clinical Neurology	Medical sciences
Critical Care Medicine	Medical sciences
Dentistry, Oral Surgery & Medicine	Medical sciences
Dermatology	Medical sciences

Table A1. (*continued*)

WoS subject category	Broad area
Emergency Medicine	Medical sciences
Endocrinology & Metabolism	Medical sciences
Gastroenterology & Hepatology	Medical sciences
Geriatrics & Gerontology	Medical sciences
Health Policy & Services	Medical sciences
Hematology	Medical sciences
Immunology	Medical sciences
Infectious Diseases	Medical sciences
Integrative & Complementary Medicine	Medical sciences
Medicine, General & Internal	Medical sciences
Medicine, Research & Experimental	Medical sciences
Microscopy	Medical sciences
Neurosciences	Medical sciences
Nursing	Medical sciences
Obstetrics & Gynecology	Medical sciences
Oncology	Medical sciences
Ophthalmology	Medical sciences
Orthopedics	Medical sciences
Otorhinolaryngology	Medical sciences
Pathology	Medical sciences
Pediatrics	Medical sciences
Peripheral Vascular Disease	Medical sciences
Pharmacology & Pharmacy	Medical sciences
Psychiatry	Medical sciences
Public, Environmental & Occupational Health	Medical sciences
Radiology, Nuclear Medicine & Medical Imaging	Medical sciences
Rehabilitation	Medical sciences
Respiratory System	Medical sciences
Rheumatology	Medical sciences
Sport Sciences	Medical sciences
Substance Abuse	Medical sciences

Table A1. (*continued*)

WoS subject category	Broad area
Surgery	Medical sciences
Toxicology	Medical sciences
Transplantation	Medical sciences
Tropical Medicine	Medical sciences
Urology & Nephrology	Medical sciences
Veterinary Sciences	Medical sciences
Acoustics	Physics
Mechanics	Physics
Optics	Physics
Physics, Applied	Physics
Physics, Atomic, Molecular & Chemical	Physics
Physics, Condensed Matter	Physics
Physics, Fluids & Plasmas	Physics
Physics, Mathematical	Physics
Physics, Multidisciplinary	Physics
Physics, Nuclear	Physics
Physics, Particles & Fields	Physics
Thermodynamics	Physics
Business	Professional fields
Business, Finance	Professional fields
Communication	Professional fields
Education & Educational Research	Professional fields
Education, Scientific Disciplines	Professional fields
Education, Special	Professional fields
Ergonomics	Professional fields
Family Studies	Professional fields
Health Care Sciences & Services	Professional fields
Hospitality, Leisure, Sport & Tourism	Professional fields
Industrial Relations & Labor	Professional fields
Information Science & Library Science	Professional fields
Law	Professional fields

Table A1. (*continued*)

WoS subject category	Broad area
Management	Professional fields
Medicine, Legal	Professional fields
Primary Health Care	Professional fields
Social Work	Professional fields
Behavioral Sciences	Psychology
Psychology	Psychology
Psychology, Applied	Psychology
Psychology, Biological	Psychology
Psychology, Clinical	Psychology
Psychology, Developmental	Psychology
Psychology, Educational	Psychology
Psychology, Experimental	Psychology
Psychology, Mathematical	Psychology
Psychology, Multidisciplinary	Psychology
Psychology, Psychoanalysis	Psychology
Psychology, Social	Psychology
Agricultural Economics & Policy	Social sciences
Anthropology	Social sciences
Area Studies	Social sciences
Criminology & Penology	Social sciences
Demography	Social sciences
Economics	Social sciences
Geography	Social sciences
Gerontology	Social sciences
International Relations	Social sciences
Linguistics	Social sciences
Planning & Development	Social sciences
Political Science	Social sciences
Public Administration	Social sciences
Social Issues	Social sciences
Social Sciences, Biomedical	Social sciences

Table A1. (*continued*)

WoS subject category	Broad area
Social Sciences, Interdisciplinary	Social sciences
Social Sciences, Mathematical Methods	Social sciences
Sociology	Social sciences
Urban Studies	Social sciences