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Research Paper

Visualization of Disciplinary Profiles: Enhanced Science Overlay Maps

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Abstract

Purpose: The purpose of this study is to modernize previous work on science overlay maps by updating the underlying citation matrix, generating new clusters of scientific disciplines, enhancing visualizations, and providing more accessible means for analysts to generate their own maps.

Design/methodology/approach: We use the combined set of 2015 *Journal Citation Reports* for the Science Citation Index (*n* of journals = 8,778) and the Social Sciences Citation Index (*n* = 3,212) for a total of 11,365 journals. The set of Web of Science Categories in the Science Citation Index and the Social Sciences Citation Index increased from 224 in 2010 to 227 in 2015. Using dedicated software, a matrix of 227 × 227 cells is generated on the basis of whole-number citation counting. We normalize this matrix using the cosine function. We first develop the citing-side, cosine-normalized map using 2015 data and VOSviewer visualization with default parameter values. A routine for making overlays on the basis of the map ("wc15.exe") is available at http://www.leydesdorff.net/wc15/index.htm.

Findings: Findings appear in the form of visuals throughout the manuscript. In Figures 1–9 we provide basemaps of science and science overlay maps for a number of companies, universities, and technologies.

Research limitations: As Web of Science Categories change and/or are updated so is the need to update the routine we provide. Also, to apply the routine we provide users need access to the Web of Science.

Practical implications: Visualization of science overlay maps is now more accurate and true to the 2015 *Journal Citation Reports* than was the case with the previous version of the routine advanced in our paper.

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Originality/value: The routine we advance allows users to visualize science overlay maps in VOSviewer using data from more recent *Journal Citation Reports*.

Keywords Science overlay maps; Science visualization; Scientometrics; Bibliometrics; Interdisciplinary research; Multidisciplinarity; Research policy; Research management

1 Introduction

This paper advances science overlay mapping processes. The intent is to provide the research communities using scientometrics with an improved methodology to generate overlay maps (Rafols, Porter, & Leydesdorff, 2010). An overlay map is a global map of science over which a subset of publications is projected, thus allowing the visualization of disciplinary scope for the scientific production of a given organization, individuals, territory, etc. Such maps can help analysts and readers grasp the mix of disciplines engaging a given topic or the portfolio of research interests reflected in the publication (sub)set of an organization (see Wallace and Rafols (2015) for a discussion of research portfolios).

The paper briefly overviews the heritage of the use of Web of Science subject categories (WCs) and of science overlay mapping. It then presents enhanced methodology to generate the maps, followed by examples to illustrate novel application opportunities. The paper updates the visualization process and provides an advanced 2015 basemap.

1.1 Efforts to Classify Research

In order to understand the multidisciplinary profile of publication sets, disciplinary or sub-disciplinary categories can be assigned to the publications. These categories can then be used to represent the position of a publication set in the overall structure of science—i.e. to overlay a specific research activity onto the map of science (Rafols, Porter, & Leydesdorff, 2010).

One method to assign publications to a disciplinary category is to rely on the journal of the publication as an estimate of the scientific field. However, disciplines and fields of science develop above the level of individual journals. Scientometricians proposed the normalization of citations in terms of journal categories (ISI Subject Categories, now known as Web of Science Categories)—as proxies of scientific fields defined above the level of individual journals—in a series of publications during the 1980s (e.g. Schubert, Glänzel, & Braun, 1986; Schubert, Glänzel, & Braun, 1989; Vinkler, 1986).

Using these categories, Moed, de Bruin, & van Leeuwenet (1995) further developed the "crown indicator" at the Center for Science and Technology Studies (CWTS) in Leiden that was later improved as the "Mean Normalized Citation Score" (MNCS). This indicator remains based on the same subject categories, and it is currently the most widely used method to provide normalized comparisons across scientific areas.

The WCs tagged to the 11,000+ journals covered by the Science Citation Index (SCI) and the Social Sciences Citation Index (SSCI) are assigned by indexers on the basis of a number of criteria, including field experts' judgment of relevance to a given field, the journal's title, and its citation patterns (Bensman & Leydesdorff, 2009). As of 2015, there are 227 WCs covering SCI and SSCI. Pudovkin and Garfield (2002) described the methods used by the ISI (then provided by Thomson Reuters, and now Clarivate Analytics), and concluded that in many fields these categories are "sufficient;" but "in many areas of research these "classifications" are crude and do not permit the user to quickly learn which journals are most closely related" (p. 1113). Boyack, Börner, and Klavans (2007) estimated that the assignment of WCs is correct in approximately 50% of cases across the file. That said, the "correct" assignment based on detailed article content would usually be proximate.

On the basis of a comparison of this classification with algorithmically generated ones, Rafols and Leydesdorff (2009) (p. 1830) concluded that the WCs can be used for aggregate statistical purposes (i.e. above 100 or so publications, depending on the desired granularity); but are not well-suited for detailed analyses (e.g. to assess an individual's research). The WCs sometimes cover similar sets of journals; for example, in the domain of biomedicine. In other cases, the categories added by an indexer cover areas that could be considered as separate sub-disciplines or subfields (Leydesdorff & Bornmann, 2016; van Eck et al., 2013). In the case of interdisciplinary publications, problems of imprecise or potentially erroneous classifications can be expected (Rafols & Meyer, 2010)[1]. Klavans and Boyack (in press) recommended using classification schemes based on fine-grained publication-level clustering; but these classifications, which we would recommend where possible, are not publicly available yet—one exception being that provided by Waltman and van Eck (2012).

Notwithstanding these issues, WCs are a main basis for scientometric analyses. The use of these journal categories has become conventional among scientometricians (e.g. Rehn et al., 2014), including use to assess research portfolios. For example, *InCites*—a customized, Web-based research evaluation tool developed by Thomson Reuters—routinely provides normalizations of citation impact using WCs for the delineation of reference sets (e.g. Costas, van Leeuwen, & Bordons, 2010; Leydesdorff, Hammarfelt, & Salah, 2011). The Flemish ECOOM unit for evaluation in Leuven (SOOI) has developed a new classification system for journals (Glänzel

[1] In scientometric evaluations, journals are sometimes attributed percentages proportional to the categories under which they are subsumed. These multiple categories have also been considered indicators of the interdisciplinarity of journals (Bordons, Bravo, & Barrigon, 2004; Katz & Hicks, 1995; Morillo, Bordons, & Gomez, 2001).

& Schubert, 2003). Other authors have refined the journal lists within specific WCs to enable a more precise evaluation of a given discipline (van Leeuwen & Calero Medina, 2012). Another journal classification system in terms of fields and subfields has been made available by Elsevier's Scopus in the meantime, but Wang and Waltman (2016) found it to be more problematic than WCs, in particular due to the high rate of multiple category assignments of a journal[2].

1.2 Description of WCs as Fields of Science

WCs can also be considered "macro-journals" representing fields and subfields of science. Their sub-disciplinary level of detail fits well with a US National Academies recommendation for study of interdisciplinarity (2005). The current (2015 WoS data) matrix of 227 WCs citing one another can be decomposed using multi-variate (e.g. clustering) analysis. It can be analyzed as a network using, for example, community-finding algorithms. Initially (refer to Leydesdorff & Rafols, 2009; Rafols, Porter, & Leydesdorff, 2010), we used 2007 data to develop a global map of science. At that time, drawing a map using the approximately 10,000 journals in the database was technically not feasible due, among other things, to the cluttering of the labels on the screen. This problem was elegantly solved by VOSviewer (which became available in 2009), by allowing interactive zoom in/out functionality in the visualization (Klavans & Boyack, 2009; van Eck & Waltman, 2010)[3].

Earlier maps were developed into an overlay-toolkit[4] that enabled users to visualize portfolios as overlays using Pajek[5] (e.g. Leydesdorff, Carley, & Rafols, 2013; Rahman et al., 2015; Riopelle, Leydesdorff, & Li, 2014; Soós and Kampis, 2011). At that time, however, further integration between community-finding algorithms (Blondel et al., 2008), network analysis (e.g. Pajek (de Nooy, Mrvar, & Batgelj, 2011)), and visualization programs such as VOSviewer and Gephi were still emerging (Waltman, van Eck, & Noyons, 2010). VOSviewer, for example, was fully integrated into Pajek in July, 2012, following incorporation of the Blondel ("Louvain") algorithm for community-finding in January of that year (Blondel et al., 2008). This algorithm offers appeal to provide an improved location of the WCs as nodes in a suitable visual rendition. The overlay process, then superimposes colored and sized nodes on top of that base to convey concentrations of activity. The enhanced science overlay mapping process provides an option to generate networking links among those nodes based on co-occurrence intensities. These can

[2] The field/subfield classification of Scopus is available in the journal list from http://www.elsevier.com/online-tools/scopus/content-overview. WCs are available (under subscription) at http://images.webofknowledge.com/WOKRS56B5/help/WOS/hp_subject_category_terms_tasca.html.
[3] Available at http://www.vosviewer.com.
[4] http://www.leydesdorff.net/overlaytoolkit
[5] Pajek is a network analysis and visualization program freely available for non-commercial usage at http://mrvar.fdv.uni-lj.si/pajek.

be rendered to augment the maps, with particular appeal to show network evolution over time for a given local domain of research activity.

We now make some choices differently from the ones we made some ten years ago. The wide use by a variety of stakeholders (including not only some researchers, but also scientometric students and practitioners) and requests for a current database, together with technical improvements in visualization during recent years, lead us to revise the overlay basemaps and toolkit based on the most recent version of the *Journal Citation Reports* (*JCR*), i.e. 2015.

2 Data and Methods

2.1 The Mapping

We use the combined set of the *JCRs* 2015 for the Science Citation Index (SCI) (*n* of journals = 8,778) and the Social Sciences Citation Index (SSCI) (*n* = 3,212) leading to a total number of 11,365 journals; 625 journals are covered by both databases (Table 1). A *JCR* for the Arts & Humanities Citation Index is not available, but, in any event, the behavior of those journals' citation practices differs considerably from that of SCI and SSCI journals (Leydesdorff, Hammarfelt, & Salah, 2011). We also note that Web of Science has expanded its coverage of other research resources, especially conference proceedings and books. Those are not included in the maps presented here.

Table 1. Numbers of journals and Web of Science categories in SCI and SSCI.

	Journals	WCS
SCI	8,778	177
SSCI	3,212	57
Sum	11,990	234
Total	11,365	227
Overlap	625	6[①]

The set of WCs covering SCI and SSCI has expanded from 224 in 2010 to 227 in 2015. The three newly added WCs are: "Audiology & speech-language pathology," "Green & sustainable science & technology," and "Logic." The former WC—"Biology, miscellaneous"—was no longer in use in 2010 and, therefore, not included in the analysis; it is also absent from the 2015 data and the current maps.

Using dedicated software, the matrix of 227 × 227 cells was generated on the basis of whole-number citation counting. As previously, we normalize this matrix using the cosine function. However, the default VOSviewer setting normalizes

[①] The journal *Language and Cognitive Processes* is additionally assigned with "OY," one of the categories of the Arts & Humanities Citation Index.

using Zitt, Bassecoulard, and Okubo's so-called "probabilistic activity index" (PAI) (2000). PAI is equal to the ratio between observed and expected values in a contingency table based on a probability calculus (Equations (1) and (2)):

$$PAI = p_{ij} \,/\, (p_i \times p_j) \tag{1}$$

$$= n_{ij} \times \Sigma_i\, \Sigma_j\, n_{ij} \,/\, \Sigma_i\, n_{ij} \times \Sigma_j n_{ij}. \tag{2}$$

In the context of VOSviewer, this measure is renamed as the "association strength" (van Eck & Waltman, 2009).

Unlike the cosine, which is symmetrical, PAI can be used to normalize asymmetrically the vertical and horizontal dimension of a matrix. However, this possible advantage is not exploited in VOSviewer because the matrix is first made symmetric using the sums of lower and upper triangle values (cellij + cellji) in a new matrix. The cosine-normalized matrix remains worth investigating, because one is able to show the difference between the citation as the current activity (citing) *versus* the cited structures as archival representations (Wouters, 1998).

Taking these issues into consideration, we first develop the citing-side, cosine-normalized map using 2015 data and VOSviewer visualization with default parameter values. This map is a "descendant" of our previous maps; strong relationship can be seen in comparing Figure 1 (our 2015 basemap from VOSviewer) with A-1 in Appendix A (the 2010 basemap from Pajek). A routine for making overlays on the basis of the map ("wc15.exe") is provided at http://www.leydesdorff.net/wc15/index.htm and described in Appendix B. If the file cosine.dbf is additionally downloaded from the website, the routine writes a value for the Rao-Stirling measure of diversity, which is a proxy of the disciplinary breadth of the publication subset (Stirling, 2007; Zhang, Rousseau, & Glänzel, 2016)[⑦,⑧] to the screen, based on using (1 – *cosine*) as the distance measure (p. 986 of Jaffe (1986)).

⑦ Rao-Stirling diversity is a measure that takes into account both the variety, balance, and the disparity of categories in a distribution. In the case of publication or patent portfolios the categories can be respectively, WCs or IPC classes. The indicator is defined as Equation (3) (Rao, 1982; Stirling, 2007):

$$\Delta = \Sigma_{ij}\, p_i\, p_j\, d_{ij}, \tag{3}$$

where d_{ij} is a disparity measure between two categories i and j and p_i is the proportion of elements assigned to each category i. As the disparity measure, we use (1 – *cosine*).

⑧ Zhang, Rousseau, and Glänzel (2016) and Garner at al. (2013) argue that $^2D^S$ provides a true diversity measure that outperforms Rao-Stirling diversity (Δ) because $^2D^S = 2.0$ is twice as diverse as $^2D^S = 1.0$. In Equation (4), these authors formulate:

$$^2D^S = 1/(1 - \Delta), \tag{4}$$

where Δ is the Rao-Stirling diversity. This improved measure varies from 1 to ∞ when Δ varies from 0 to 1. The transformation is monotonic and the value of $^2D^S$ follows directly from that of the Rao-Stirling diversity using Equation (3).

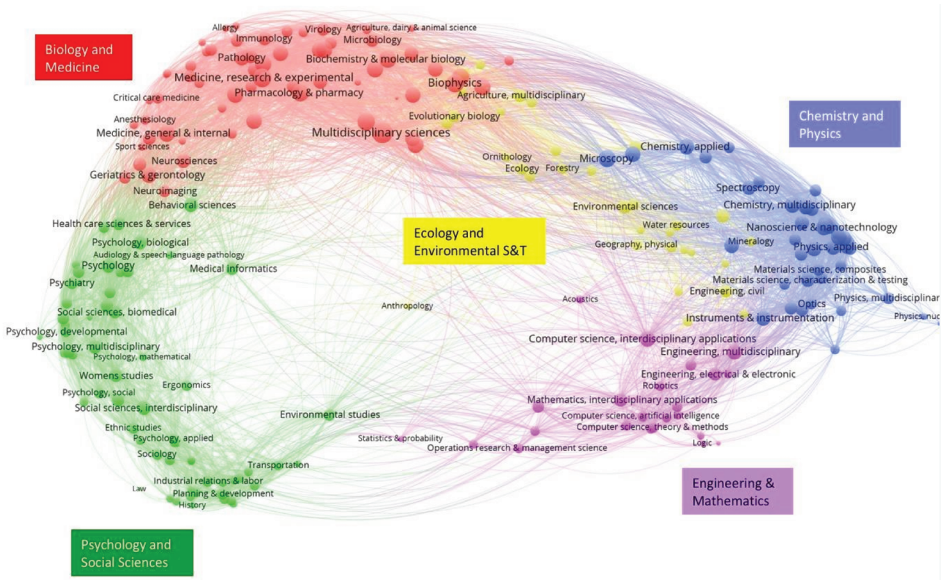

Figure 1. Five-cluster basemap for 2015 (based on VOSviewer)[⑨].

As an additional resource, one can feed the citation matrix of 227 WCs (citing *versus* cited, but without prior normalization) into VOSviewer and develop a similar map (Appendix A, Figure A-2). Analogous routines as wc15.exe are provided by mtrx15.exe that produces a file "mtrx15.csv" as an input file for the mapping of a portfolio in VOSviewer using the non-normalized citation data (Figure A-2). In the case of a non-normalized matrix, a distance measure is not provided: the number of possible similarity criteria is large (see Klavans & Boyack (in press), and US National Academies (2005)) and the choice can be left to the user (using, for example, SPSS).

The routines also provide cluster and vector files for cos15.paj and matrix.paj made available on the website for Pajek, respectively (as previously). Pajek and Gephi contain a suite of tools for network analysis and visualization such as various decompositions, layouts, and visualization options. Using Pajek or Gephi, for example, one can also obtain the results of the Louvain algorithm (Blondel et al., 2008) for the decomposition in a format that can again be visualized in programs such as VOSviewer or Gephi.

⑨ This map can be Web-started at http://www.vosviewer.com/vosviewer.php?map=http://www.leydesdorff.net/wc15/cos015m.txt&network=http://www.leydesdorff.net/wc15/cos015n.txt&label_size_variation=0.5&scale=1&colored_lines&curved_lines&n_lines=10000.

Using VOSviewer, the user can change the number of clusters by changing the resolution parameter and running the clustering algorithm again. Using default values, both maps (i.e. cosine-normalized or not) show five clusters, but chi-square statistics reject the zero-hypothesis that the two classifications are similar (Cramer's $V = 0.707$; $p < 0.01$). The corresponding five colors (blue, red, green, yellow, and pink) will also be used for the overlays, but the user can change this. Changing the granularity requires one to import the file with network data. More detailed instructions can be found in Appendix B and at http://www.leydesdorff.net/wc15/index.htm.

2.2 Measures of Disciplinary Diversity

As mentioned in the previous section, the cosine-similarity matrix for the WCs provides both the basis for locating the WCs as nodes in science maps (Figure 1), and the basis to calculate measures of diversity. Footnotes 7 and 8 remind the users of Stirling's measure and how it can be calculated using the 227-by-227 WC cosine-similarity matrix (see Rafols, Porter, & Leydesdorff (2010) for details).

Porter and colleagues introduced measures of interdisciplinarity and multidisciplinarity called "Integration scores" and "Specialization scores," extended by Carley and Porter to "Diffusion scores" as well (Carley & Porter, 2012; Porter et al., 2007; Porter & Rafols, 2009). For a given set of publication from WoS, Specialization scores indicate the disciplinary diversity of the set based on the distribution of their WCs. Integration scores reflect the diversity of those publications' cited references—again, using the cited WCs. Downloading the "cited references" of a given WoS search set allows one to pursue this metric. Conversely, Diffusion scores reflect the diversity of the disciplines citing a given set of papers, based on the citing journals' WCs. This requires a citation search and data downloading from WoS.

These scores are different instances of the Rao-Stirling diversity measures (Footnote 7) (Stirling, 2007). As introduced earlier in this section, one can obtain the Specialization score (Rao-Stirling diversity for the WCs represented in the WoS search set) along with a science overlay map if desired, directly from the script provided at http://www.leydesdorff.net/wc15.

Integration or Diffusion scores need more detailed computation. Scripts have been prepared to run in VantagePoint software[9].

2.3 Mapping Options

As what is introduced earlier in this paper, and enabled at the website (http://www.leydesdorff.net/wc15), one can perform a topical search at WoS and take the

[9] Scripts available at http://www.vpinstitute.com/.

output as an "analyze.txt" file to enter directly at the site to generate the corresponding science overlay map in VOSviewer. And, as noted, one can vary the resulting overlay maps in several ways in VOSviewer to accentuate points of interest[11].

The website provides the option to generate either five-cluster science overlay maps or finer scaled (color-differentiated) 18-cluster overlay maps. Both cluster solutions were generated in VOSviewer, using its algorithm[12]. Appendix map A-3 shows the 18-cluster basemap. Appendix map A-4 shows an overlay for the London School of Economics as an example.

3 Case Examples

Our intent here is to present a range of maps to illustrate differences that the new science overlay mapping can convey. We hope that these promote thinking of additional uses of science overlay mapping, potentially augmented by enabling calculation of diversity measures (e.g. Specialization and Integration scores) with the same tool suite.

Figures 2 and 3 compare two multinational companies' research publications in WoS for 2010–2015. Both show biomedical and physical science strengths. Unlike Unilever, Pfizer also has a pronounced portfolio in "economics" and "statistics and probability" as fields of science. These visualizations facilitate exploration of shared and complementary research interests, potentially of use in considering collaboration (as well as tracking competition) among organizations or nations.

Figures 4, 5, and 6 present three contrasting university profiles. Patterns stand out quite boldly among the engineering-oriented Georgia Tech, the social science emphases of the London School of Economics, and the full spectrum University of Amsterdam research. In contrast to Figure 5, Figure A-4 (Appendix) presents the same data using an 18-cluster map that facilitates finer comparisons.

Usually one would want to focus more tightly—e.g. on a particular research unit or even on an individual researcher's work (say to ascertain complementarity with another research group or emphases of a funding program). As one step in that direction, contrast the emphases seen in Figure 4 to its subset for one department of Georgia Tech, the School of Public Policy, shown in Figure 7.

[11] Another way to compute the maps is to use VantagePoint (http://www.thevantagepoint.com) to process a search set downloaded from WoS. If one mainly wants a science overlay map of the full search set as is, it is easier to output the "analyze.txt" file from WoS for entry into http://www.leydesdorff.net/wc15. However, if you have cause to process the search set data further, VantagePoint provides helpful tools to facilitate data cleaning (e.g. to remove inappropriate items from the search set) or to analyze sub-data sets (e.g. to compare what selected organizations have published on, say, nanotechnology).

[12] Our previous clustering solutions were generated using factor analyses in SPSS, resulting in 4 "meta-disciplines" (see Appendix Figure A-1) and 19 "macro-disciplines" for 2010 base data.

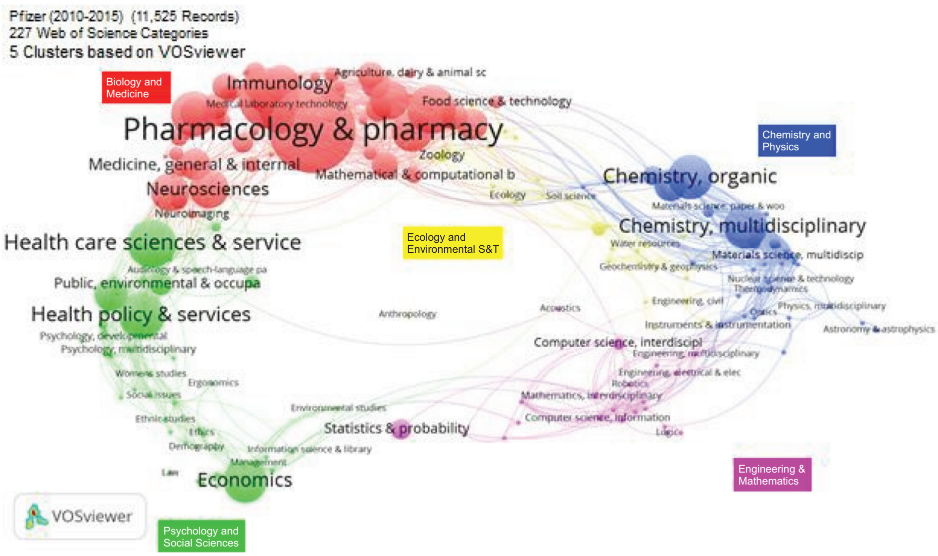

Figure 2. Science overlay map for Pfizer.

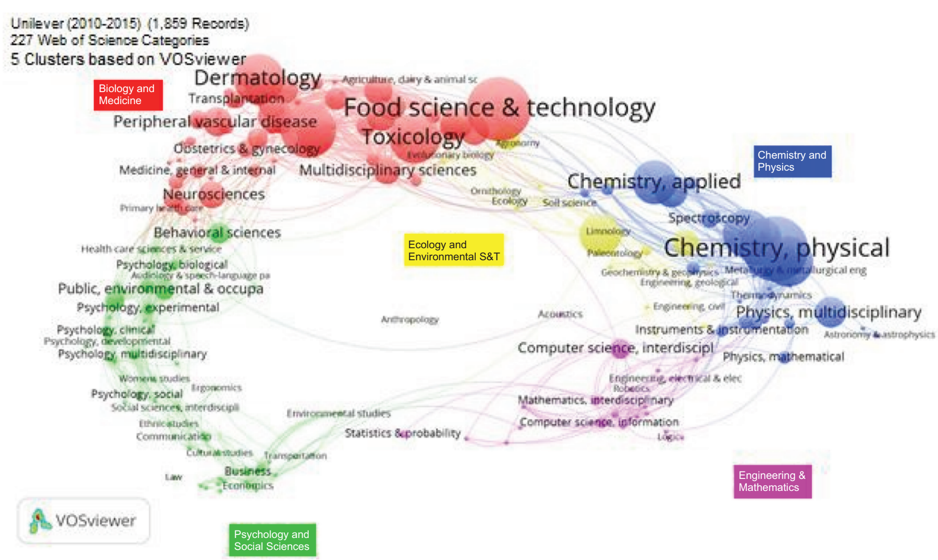

Figure 3. Science overlay map for Unilever.

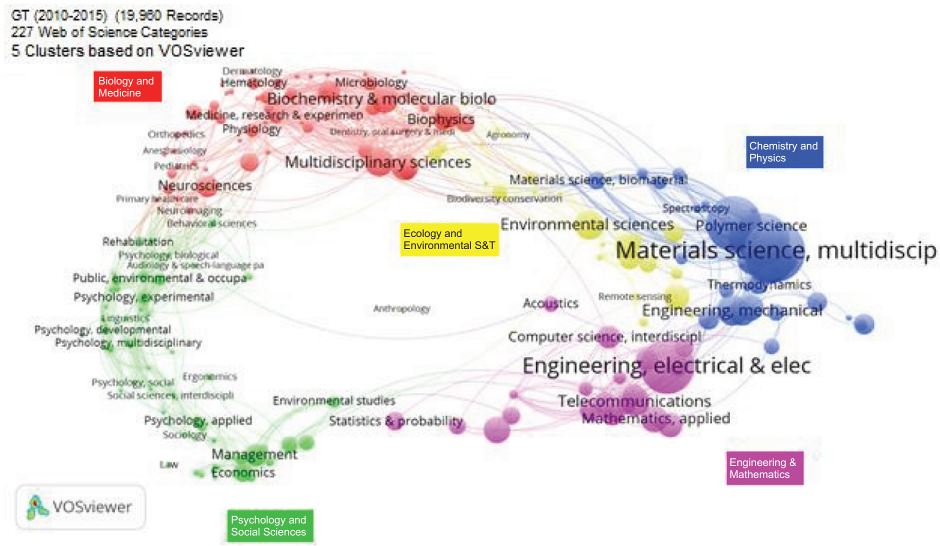

Figure 4. Science overlay map for Georgia Tech.

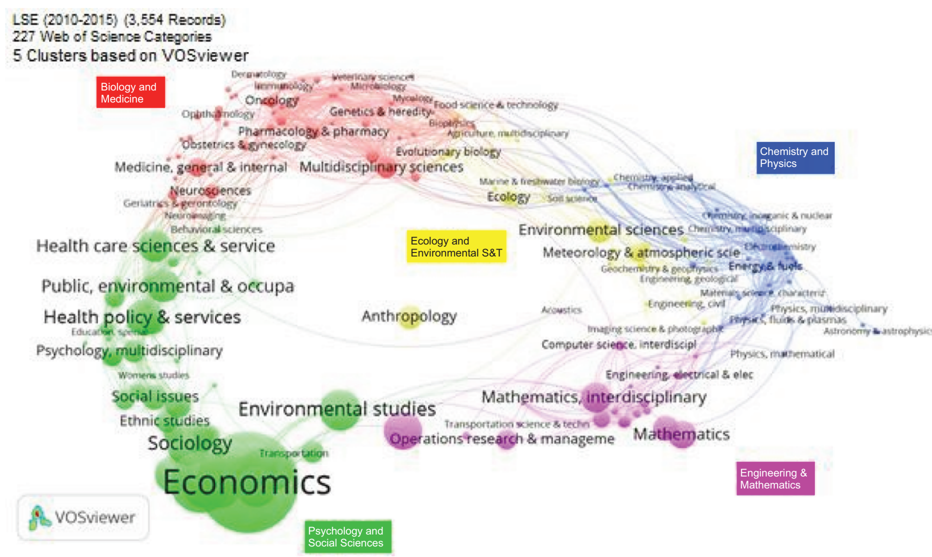

Figure 5. Science overlay map for the London School of Economics.

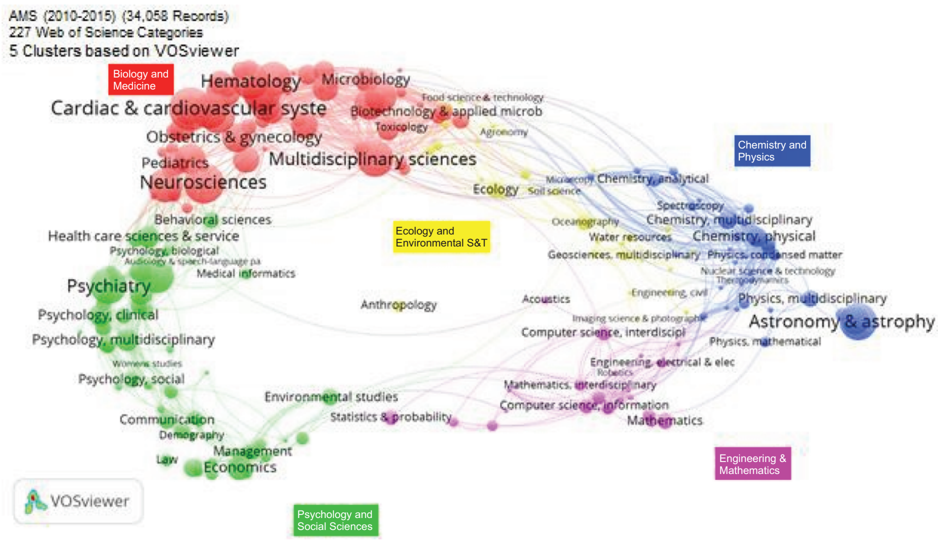

Figure 6. Science overlay map for the University of Amsterdam.

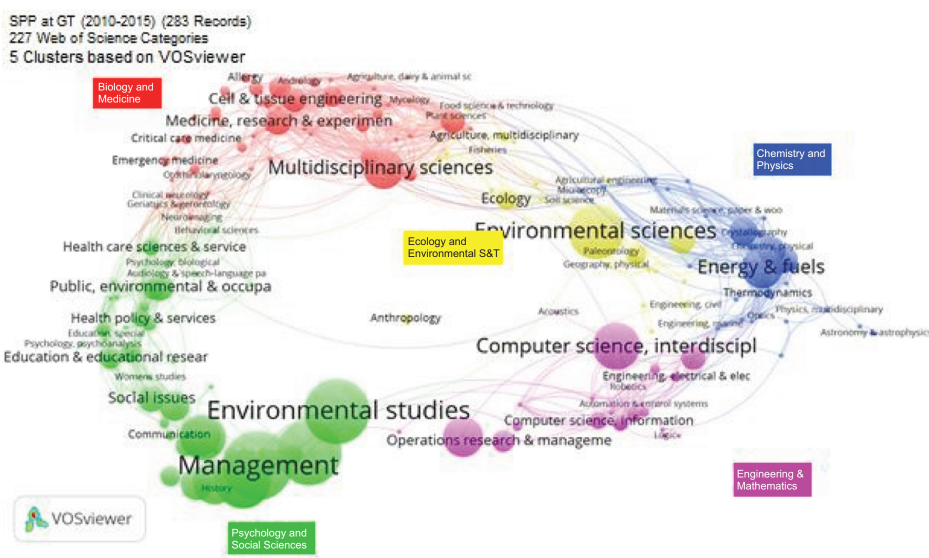

Figure 7. Science overlay map for the School of Public Policy, Georgia Tech.

Conversely, one can observe even broader research profiles—Figure A-5 does so for a country, South Africa. Not surprisingly, one sees a very broad spectrum of research activity at this level. One could pursue via further analyses—e.g. to identify researchers active in a particular sub-domain as spotted on a map. We envision various uses for such technical intelligence, ranging from identification of others pursuing one's area of interest to identifying complementary strengths for research center development, or such.

Figures 2 to 7 map the research outputs of a given organization. One can map other WoS search sets as well. For instance, in a study of the outputs and impacts of an NSF research program on Human & Social Dynamics (HSD), science overlay mapping was useful for those assessing the merits of that program to see the diversity of the publications generated by HSD support. However, it was even more interesting to see the spread of papers citing those publications across the disciplines. Those showed that this funding from the Social, Behavioral & Economic Sciences Directorate was actively cited beyond those social sciences by natural sciences and engineering (Garner et al., 2013).

Another appealing opportunity arises in mapping topical searches. Figure 8 illustrates for an emerging energy technology, dye-sensitized solar cells (DSSCs), dominated by materials science and related research. "Big Data" (using a first approach) (Figure 9) shows a strong concentration in Computer Science and related fields, but note the incredible breadth of publication as virtually all fields consider how Big Data and Analytics can enhance their R&D. Such research profiling could support funding agencies' confirmation of interdisciplinary research programs.

4 Discussion

This article bolsters science overlay mapping as a tool for researchers and analysts to help understand the disciplinary profiles of organizations, funding programs, topics, or other types of publication sets. Visualization of the disciplinary profile, operationalized at the sub-discipline level of 227 Web of Science Categories (WCs) can now offer an adjustable, "birds eye" view of the fields involved. By choosing the 18-cluster option (Figure A-3) or the five-cluster option (Figure 1), one can show the analysis at a narrow or broad disciplinary description.

We use a cosine-normalized basemap in this paper's examples, but note the option of a non-normalized matrix that can default to VOSviewer's internal normalization scheme for a different presentation (e.g. Figure A-2). We favor the cosine-normalization as 1) yielding more intuitive results, 2) consistent with our prior overlay maps (see Figure A-1), 3) and shown to be consistent with consensus science mapping (e.g. various renditions by Klavans & Boyack (in press), and others

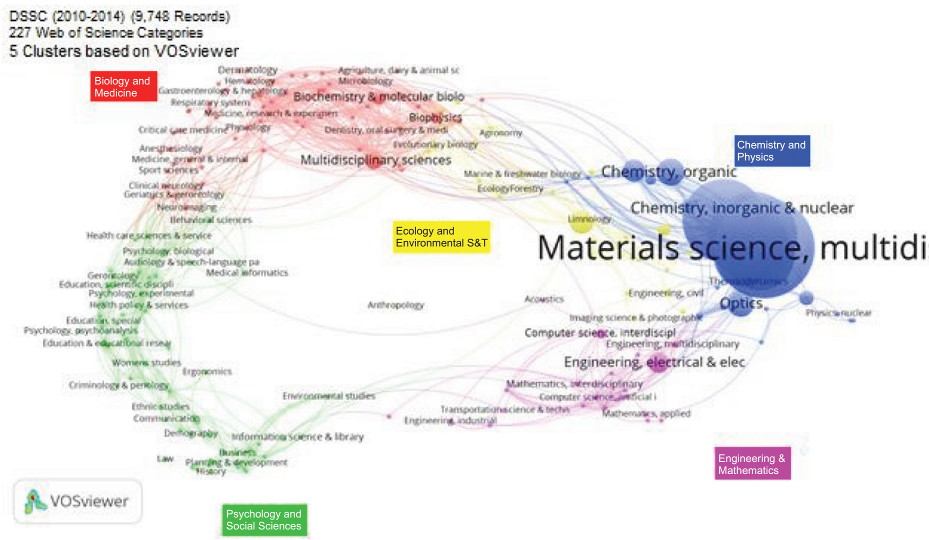

Figure 8. Science overlay map for dye-sensitized solar cells.

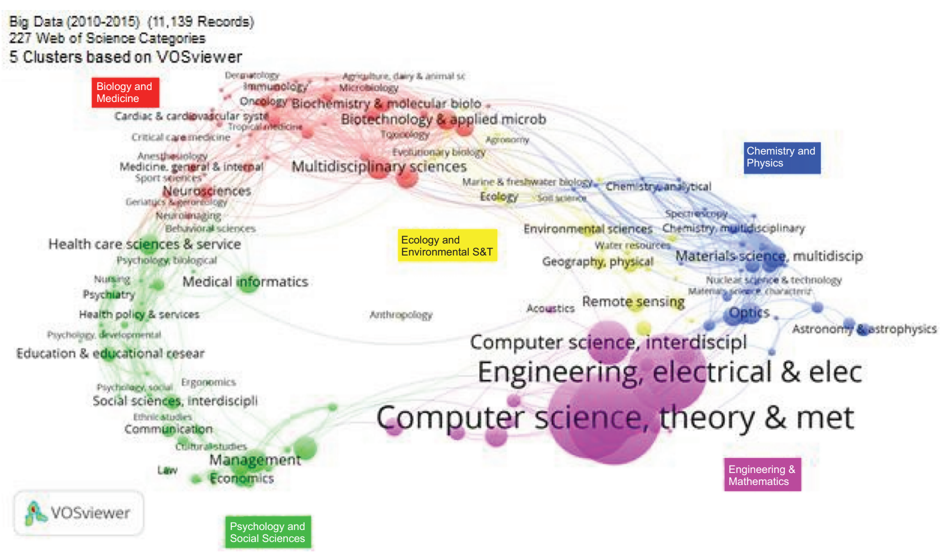

Figure 9. Science overlay map for “Big Data.”

(Klavans, & Boyack, 2009), and 4) conducive to use as a diversity measure in calculating diversity indexes (Rao-Stirling). Comparing to Figure A-1 also shows the general continuity between the previous Pajek visualization to the current VOSviewer one. It also shows some differences, both in the visual rendition and in node localizations. We now favor VOSviewer for its ease of use and accessible richness of the visualization options.

As illustrated in the case examples, these science overlay maps can provide a quick and intuitive perspective on the disciplinary profiles of organizations. As explained in Rafols, Porter, and Leydesdorff (2010) (see also Leydesdorff & Bornmann, 2016; Rafols & Leydesdorff, 2009; Rafols & Meyer, 2010; van Eck et al. 2013), the main downside of this visualization tool is the lack of accuracy in the WCs—which nevertheless is the most widely used and easily available classification system. As shown in a previous study (Rafols, Porter, &Leydesdorff, 2010), the lack of accuracy of WCs is less problematic at a relatively high level of aggregation. Most errors in locating specific research are nearby in the mapping. For fine-grained descriptions, article-based clustering is preferred (Waltman & van Eck, 2012). However, that does not match the WC-based mapping for communication of which fields are engaged, to what degree.

We believe these new science overlay maps open opportunities for future research. For one, exploration of the differences between the global science maps over time (e.g. between 2010 and 2015 basemaps), shows promise to elucidate real shifts in global research emphases. For instance, is medical science becoming more closely related to biological sciences and less linked to chemistry? The basemaps appear to evolve slowly as shown by the fact that the underlying 2010 and 2015 citation matrices among WCs are very similar (QAP correlation $r = 0.937$; $p < 0.001$) in spite of considerable changes in WoS journal inclusion over that period. This justifies their use for overlays over a certain temporal range.

In stepping through the case analyses, we have pointed to a variety of appealing applications for the science *overlay* mapping. We believe the enhanced clustering of the WCs, improved visualization, and simplified processing will enable various scientometric applications. We do not repeat those here, but note a synergistic capability offered by the integrated data processing hereby enabled. Namely, analysts can now treat multiple aspects of cross-disciplinary engagement in tandem—science overlay mapping, social network analyses (e.g. by comparing connection strengths among WC nodes over time), and diversity (e.g. through calculation of Specialization, Integration, and/or Diffusion scores).

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Author Contributions

All authors on this manuscript made material and significant contributions to its production. L. Leydesdorff (loet@leydesdorff.net) and I. Rafols (i.rafols@ingenio.upv.es) made the most significant contributions to the development of the procedure used in this study (which is made available at L. Leydesdorff's website). A.L. Porter (alan.porter@isye.gatech.edu) and S. Carley (stephen.carley@searchtech.com, corresponding author) applied these procedures and produced visuals for the same to numerous universities, companies, and technologies. S. Carley developed a script that runs the procedure advanced in this study from software called VantagePoint (see www.thevantagepoint.com). All authors invested significant time drafting and redrafting the text of this work, but A.L. Porter produced the lion's share of the article's main text.

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Appendix A

Here is the 2010 science basemap showing four "meta-clusters" of disciplinary nodes. We also used a 19 "macro-cluster" version of the same nodes grouped into finer sets. The "clustering" for 2010 was done using factor analysis in SPSS from the citing-to-cited WC matrix.

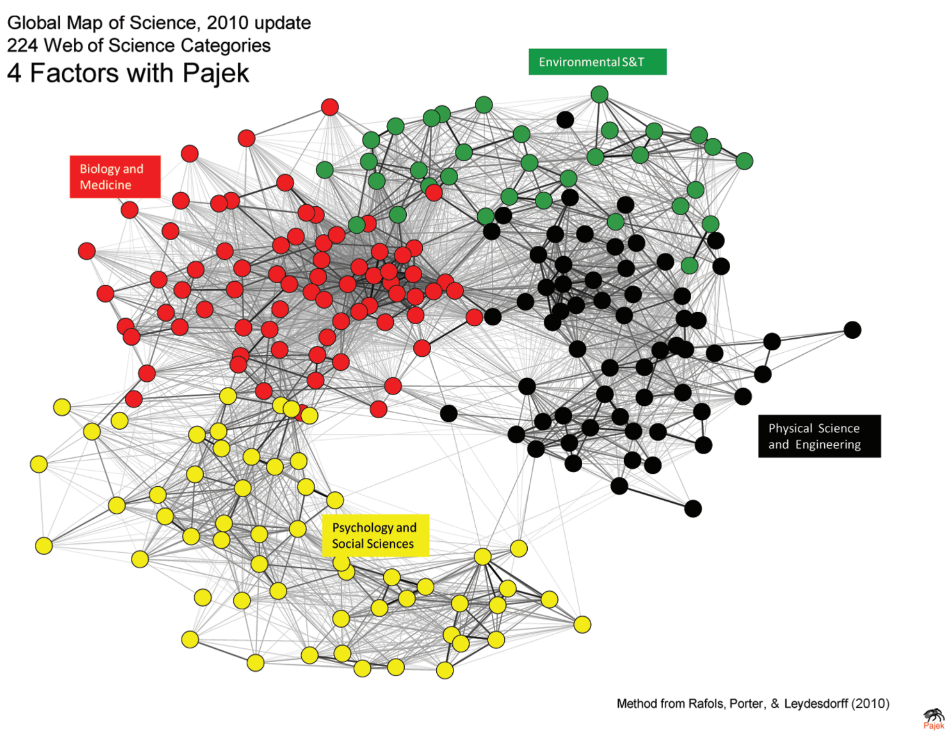

Figure A-1. Basemap 2010, using Pajek with a four-factor analysis decomposition.

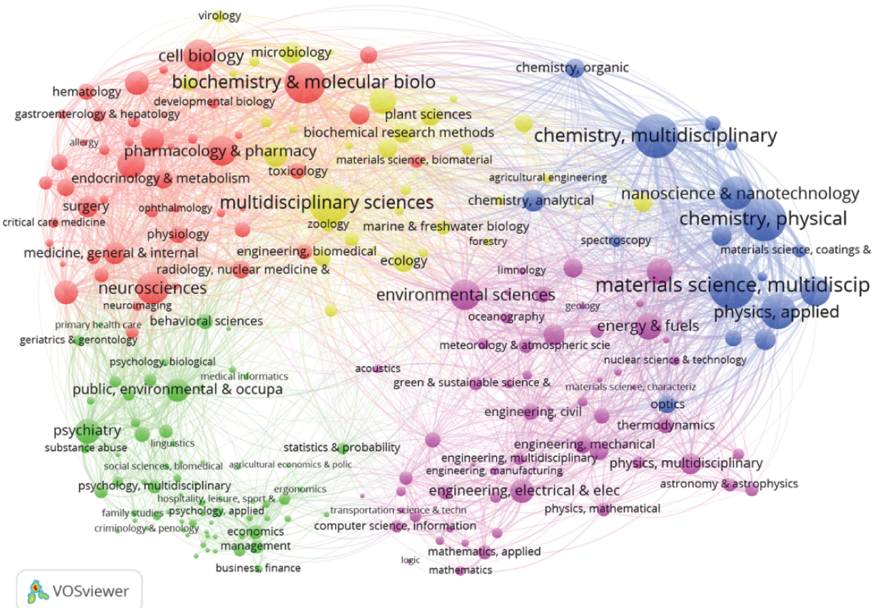

Figure A-2: Basemap 2015, using VOSViewer with a five-cluster decomposition. Settings: Attraction 2, Repulsion 0[⑬].

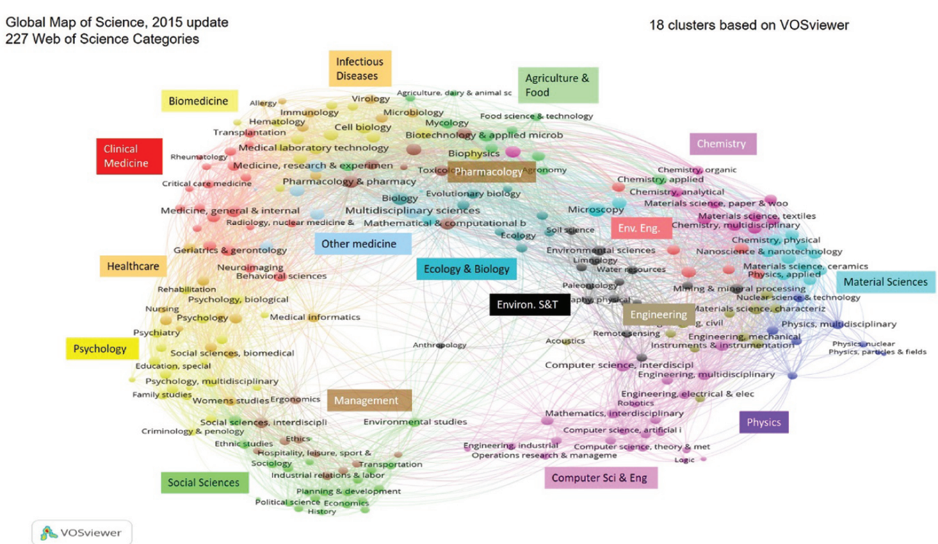

Figure A-3. 2015 basemap with a 18-cluster decomposition.

⑬ This file can be web-started at http://www.vosviewer.com/vosviewer.php?map=http://www.leydesdorff.net/wc15/mtrxmap.txt&network=http://www.leydesdorff.net/wc15/mtrxnet.txt&label_size_variation=0.3&scale=1&colored_lines&curved_lines&n_lines=10000.

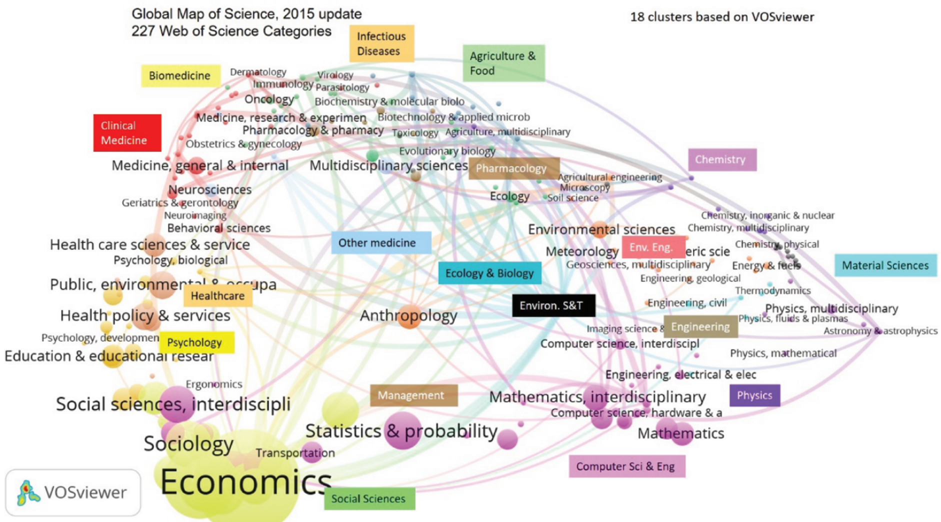

Figure A-4. 18-cluster science overlay map for the London School of Economics (LSE).

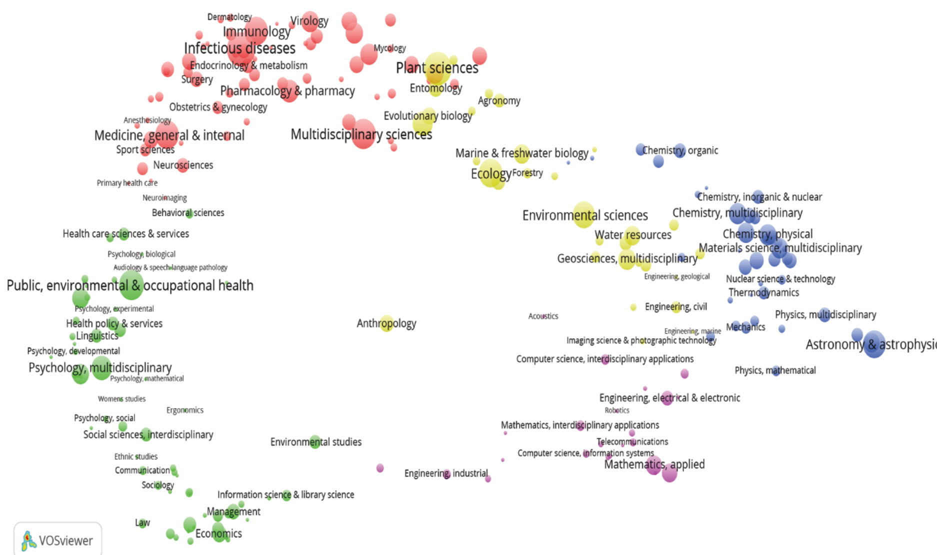

Figure A-5. Science overlay map for South Africa (based on 72,937 records in a simple search on cu = South Africa for 2010–2015 in SCI+SSCI).

Appendix B: Creating Your Own Science Overlay Maps

The steps described below rely on access to the Web of Science and the files available on (and downloadable from) http://www.leydesdorff.net/wc15. The objective is to obtain the set of Web-of-Science Categories (WCs) of the journals of a given set of documents; provide this set to a network visualization software; and output the overlay information to a robust basemap of the science structure (see Rafols, Porter, & Leydesdorff (2010) for a description of the concept). We describe below the procedures for using Pajek and/or VOSviewer. However, Pajek files can also be read by Gephi, UCInet, and most other network analysis and visualization software.

First, the analyst has to conduct one's own search in the Web of Science of Thomson Reuters[14]. Users should note that this initial step is crucial and should be done carefully: author names, for example, can be retrieved with different initials; addresses are sometimes inaccurate, and only some types of document, may be of interest (e.g. only so-called citable items: *articles*, *proceedings papers*, and *reviews*). Once the analyst has chosen a set of documents from searches at Web of Science, one can click the tab, *Analyze results* at the right top of the results page. At a new webpage, the selected document set can then be analyzed along various criteria (top left hand tab). The Web of Science Category choice produces a list with the number of documents in each Category. The resulting list can be downloaded into a file with the default name *analyze.txt*. See Riopelle's step by step tutorial[15] for a detailed description of the process.

The file "analyze.txt"—make sure that the file has this name!—can be transformed by the program at http://www.leydesdorff.net/wc15/wc15.exe to a WC15.ve for upload as a vector into Pajek, and to the file *vos.csv* for use in VOSviewer. When using the wc15.exe script, one has to download the file (http://www.leydesdorff.net/wc15/cos_map.dbf) in the same folder.

Rao-Stirling diversity and Zhang, Rousseau, & Glänzel's (2016) measure of true diversity are provided on screen if the file (http://www.leydesdorff.net/wc15/cosine.dbf) is made available (downloaded) in the same folder as the files analyze.txt (downloaded from WoS), cos_map.dbf, and the routine WC15.exe.

VOSviewer

The easiest way to generate a science map is to use the visualization program VOSviewer. Click on the "Open" tab in VOSviewer. The program WC15.exe generates the file *vos.csv* which can be opened in VOSviewer as a so-called "map-files." (the extension "csv" stands for "comma-separated variables;" the file can be edited both in Excel and using a text editor.) One is advised to consult the VOSviewer

[14] www.webofknowledge.com
[15] Available at http://www.leydesdorff.net/wc15.

manual (in the left pane of the program after installation) for further options such as different colouring.

For experienced users, the so-called network file, which provides information on the similarity between WoS Categories as the edges of the network, is available from http://www.leydesdorff.net/wc15/cos015n.txt. Loading this file into VOSViewer enables the user to run the program with different parameters (see also Leydesdorff & Rafols (2012)).

Pajek

One can download and install the freeware program Pajek for network analysis and visualizations. After opening this program, press F1 and read the basemap[16] (after downloading). Then, go to the main menu *File>Vector>Read* to upload the above prepared file "WC15.vec." Selecting from the menu *Draw>Draw-Partition-Vector* (alternatively, pressing *Ctrl-Q*), the overlay map is generated.

At this stage, the size of nodes will often need adjustment, which can be done by selecting *Options>Size of Vertices* in the new draw window. *Crtl-L* and *Ctrl-D* allow users to visualize and delete, respectively, the labels. The cluster file wc15.cls is also generated and allows for the *Options>Mark vertices using>Mark cluster only* in the drawing screen of Pajek. Clicking on nodes allows moving WCs to other positions. The image can be exported selecting *Export>2D>* in the menu of the *Draw* window.

Rao-Stirling Diversity

WC15.exe also generates the file wc15.dbf. This file contains the distribution of WCs and can thus be used as input to the computation of the Rao-Stirling diversity ($\Delta = \Sigma_{ij} p_i p_j d_{ij}$) and Zhang, Rousseau, & Glänzel's (2016) measure of true diversity ($^2D^S = 1/(1 - \Delta)$) *if* the file[17] is downloaded to the same folder. The file cosine.dbf is needed because the value ($1 - cos(ij)$) is used as the cognitive distance between WCs i and j.

The materials (citation matrix, cosine matrix, and classification scheme) are available at http://www.leydesdorff.net/matrix15.xlsx.

Appendix C: Details on Data Searches for the Example Maps

Several searches use Web of Science's "organization-enhanced" feature to capture recognized name variations.

Many of the searches were conducted inclusively—e.g. for all years, for all available Web of Knowledge databases. We examined results and then, unless

[16] http://www.leydesdorff.net/wc15/map15.paj.
[17] http://www.leydesdorff.net/indicators/cosine.dbf.

otherwise noted, used VantagePoint to reduce the record set used in making the science overlay maps to SCI + SSCI, usually for 2010–2015.

For Pfizer, for instance, we compared the WC set for SCI+SSCI *vs*. that for all Web of Knowledge databases available at Georgia Tech. Notably, that includes Arts & Humanities Citation Index (A&HCI), Science and Social Science conference proceedings, and book citation index items as well. For Pfizer this added 2,757 records to the 11,525 located by searching just in SCI+SSCI. However, 2,443 are duplicates of SCI+SSCI records, so the net addition is 314 records. Those records are associated with 612 WC instances (recall that some journals are associated with multiple WCs). So this would alter the resulting maps. We compared for Pfizer and the differences are small.

Unless otherwise noted, the searches were conducted in August or September, 2016.

Web of Science Search for University of Amsterdam (AMS) Publications

You searched for: **ORGANIZATION-ENHANCED:** ((AMSTERDAM UNIV AND University of Amsterdam) OR (AMSTERDAM UNIV LIB AND University of Amsterdam) OR (BIJ UNIV AMSTERDAM AND University of Amsterdam) OR (BIOCENTRUM UNIV AMSTERDAM AND University of Amsterdam) OR (CHEMIEWINKEL UNIV AMSTERDAM AND University of Amsterdam) OR (CTR UNIV AMSTERDAM AND University of Amsterdam) OR (GEMEENTE UNIV AMSTERDAM AND University of Amsterdam) OR (GEMEENTELIJKE UNIV AMSTERDAM AND University of Amsterdam) OR (INHOLLAND UNIV AMSTERDAM AND University of Amsterdam) OR (NETSPAR UNIV AMSTERDAM AND University of Amsterdam) OR (RES UNIV AMSTERDAM AND University of Amsterdam) OR (RIJKSUNIV AMSTERDAM AND University of Amsterdam) OR (U AMSTERDAM AND University of Amsterdam) OR (UNI AMSTERDAM AND University of Amsterdam) OR (UNIV AMSTERDAM AND University of Amsterdam) OR (UNIV AMSTERDAM 1 AND University of Amsterdam) OR (UNIV AMSTERDAM G1 106 AND University of Amsterdam) OR (UNIV AMSTERDAM IBED AND University of Amsterdam) OR (UNIV AMSTERDAM IBIS UVA AND University of Amsterdam) OR (UNIV AMSTERDAM LIB AND University of Amsterdam) OR (UNIV AMSTERDAM MED INFORMAT AND University of Amsterdam) OR (UNIV AMSTERDAM MED PHYS LAB AND University of Amsterdam) OR (UNIV AMSTERDAM MEDIA STUDIES AND University of Amsterdam) OR (UNIV AMSTERDAM NETSPAR AND University of Amsterdam) OR (UNIV AMSTERDAM NIKHEF AND University of Amsterdam) OR (UNIV AMSTERDAM NUTR DIETET AND University of Amsterdam) OR (UNIV AMSTERDAM POLIT SCI BIOL AND University of Amsterdam) OR (UNIV AMSTERDAM SANQUIN RES AND University of Amsterdam) OR (UNIV AMSTERDAM TAALWETENSCHAP AND

University of Amsterdam) OR (UNIV AMSTERDAM UVA AND University of Amsterdam) OR (UNIV AMSTERDAM WILHELMINA GASTHUIS AND University of Amsterdam) OR (UNIV AMSTERDAM ZOOL LAB AND University of Amsterdam) OR (UVA UNIV AMSTERDAM AND University of Amsterdam) OR (UVA AMSTERDAM AND University of Amsterdam) OR (ZOOL UNIV AMSTERDAM AND University of Amsterdam)) AND **YEAR PUBLISHED:** (2010–2015)

Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.

Web of Science Search for Georgia Tech Publications

ORGANIZATION-ENHANCED: ((Georgia Institute of Technology OR Georgia Institute of Technology OR (GEORGIA INST TECH AND Georgia Institute of Technology) OR (GEORGIA INST TECH LIB INFORMAT CTR AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL 325716 AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL CIVIL ERVIRONM ENGN AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL ELECT COMP ENGN AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL EMORY AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL EMORY UNIV AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL GEORGIA TECH AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL IND SYST ENGN AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL ITERATED SYST AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL LIB AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL LIB INFORMAT CTR AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL SAVANNAH AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL SPACE SCI TECHNOL AND Georgia Institute of Technology) OR (GEORGIA INST TECHNOL TECH AND Georgia Institute of Technology) OR (GEORGIA TECH AND Georgia Institute of Technology) OR (GEORGIA TECH ATHLET ASSOC AND Georgia Institute of Technology) OR (GEORGIA TECH ATHLET DEPT AND Georgia Institute of Technology) OR (GEORGIA TECH ATHLETIC ASSOC AND Georgia Institute of Technology) OR (GEORGIA TECH COLL COMP AND Georgia Institute of Technology) OR (GEORGIA TECH ECE AND Georgia Institute of Technology) OR (GEORGIA TECH ECON DEV INST AND Georgia Institute of Technology) OR (GEORGIA TECH ECON DEV TECHNOL VENTURES AND Georgia Institute of Technology) OR (GEORGIA TECH EES AND Georgia Institute of Technology) OR (GEORGIA TECH EMORY AND Georgia Institute of Technology) OR (GEORGIA TECH EMORY BIOMED

ENGN AND Georgia Institute of Technology) OR (GEORGIA TECH EMORY BIOMED ENGN DEPT AND Georgia Institute of Technology) OR (GEORGIA TECH EMORY CTR ENGN LIVING TISSUED AND Georgia Institute of Technology) OR (GEORGIA TECH EMORY CTR ENGN LIVING TISSUES AND Georgia Institute of Technology) OR (GEORGIA TECH EMORY DEPT BIOMED ENGN AND Georgia Institute of Technology) OR (GEORGIA TECH EMORY UNIV AND Georgia Institute of Technology) OR (GEORGIA TECH FUS RES CTR AND Georgia Institute of Technology) OR (GEORGIA TECH IBB AND Georgia Institute of Technology) OR (GEORGIA TECH INTERACT MEDIA TECHNOL CTR AND Georgia Institute of Technology) OR (GEORGIA TECH LIB AND Georgia Institute of Technology) OR (GEORGIA TECH LIB INFORMAT CTR AND Georgia Institute of Technology) OR (GEORGIA TECH REG ENGN PROGRAM AND Georgia Institute of Technology) OR (GEORGIA TECH RES CORP AND Georgia Institute of Technology) OR (GEORGIA TECH RES INST AND Georgia Institute of Technology) OR (GEORGIA TECH SAVANNAH AND Georgia Institute of Technology) OR (GEORGIA TECHNOL RES INST AND Georgia Institute of Technology)) AND **YEAR PUBLISHED:** (2010–2015)

Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, CCR-EXPANDED, IC.

Web of Science Search for London School of Economics (LSE) Publications

You searched for: ORGANIZATION-ENHANCED: ((LON SCH ECON AND London School Economics & Political Science) OR (LOND SCH ECON AND London School Economics & Political Science) OR (LONDON ECON SCH AND London School Economics & Political Science) OR (LONDON SCH ECON AND London School Economics & Political Science) OR (LONDON SCH ECON A450 AND London School Economics & Political Science) OR (LONDON SCH ECON CONSULTANT AND London School Economics & Political Science) OR (LONDON SCH ECON CTR AND London School Economics & Political Science) OR (LONDON SCH ECON LSE AND London School Economics & Political Science) OR (LONDON SCH ECON MEDIA COMMUN AND London School Economics & Political Science) OR (LONDON SCH ECON PINPOINT ANAL LTD AND London School Economics & Political Science) OR (LONDON SCH ECON POLIT AND London School Economics & Political Science) OR (LONDON SCH ECON POLIT SCI AND London School Economics & Political Science) OR (LONDON SCH ECON POLIT SCI LSE AND London School Economics & Political Science) OR (LONDON SCH ECON POLIT SCI RES AND London School Economics & Political Science) OR (LONDON SCH ECON POLITICAL

SCI AND London School Economics & Political Science) OR (LONDON SCH ECON SOCIAL POLIT SCI AND London School Economics & Political Science) OR (LONDON SCH ECON SOCIAL SCI AND London School Economics & Political Science) OR (LONDON SCH ECON SOCIOL AND London School Economics & Political Science) OR (LONDON SCH ECON UNITED KINGDOM AND London School Economics & Political Science) OR (LONDON SCH ECONOM AND London School Economics & Political Science) OR (LONDON SCH ECONOM POLIT SCI AND London School Economics & Political Science) OR (LONDON SCH ECONOMICS AND London School Economics & Political Science) OR (LONDON SCH POLIT ECON AND London School Economics & Political Science) OR (LONDONS SCH ECON AND London School Economics & Political Science) OR (LONS SCH ECON AND London School Economics & Political Science) OR (LONSON SCH ECON AND London School Economics & Political Science) OR (LSE AND London School Economics & Political Science) OR (LSE CTR STUDY HUMAN RIGHTS AND London School Economics & Political Science) OR (LSE DEPT INT RELAT AND London School Economics & Political Science) OR (LSE FINANCIAL MKT GRP AND London School Economics & Political Science) OR (LSE GENDER INST AND London School Economics & Political Science) OR (LSE GLOBAL GOVERNANCE AND London School Economics & Political Science) OR (LSE HLTH AND London School Economics & Political Science) OR (LSE HLTH SOCIAL CARE AND London School Economics & Political Science) OR (LSE PERSONAL SOCIAL SERV RES UNIT AND London School Economics & Political Science) OR (LSE SOCIAL POLICY AND London School Economics & Political Science) OR (LSE STICERD AND London School Economics & Political Science)) AND **YEAR PUBLISHED:** (2010–2015)

Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.

Web of Science Search for Pfizer Publications

You searched for: ORGANIZATION-ENHANCED: (((PHARMACOKINET PHARMACODYNAM DRUG METAB PFIZER I AND Pfizer) OR (PRICING REIMBURSEMENT AUTHOR DEPT PFIZER AND Pfizer) OR (ABT MIKROBIOL H MACK ZOONOSIS PFIZER AND Pfizer) OR (BIOTHERAPEUT PHARMACEUT SCI PFIZER INC AND Pfizer) OR (INFLAMMAT IMMUNOL MED CHEM PFIZER AND Pfizer) OR (ACROSTUDY MED OUTCOMES PFIZER ENDOCRINE CARE AND Pfizer) OR (H MACK NACHF GMBH CO PFIZER AND Pfizer) OR (PARKE DAVIS R D DEPT PFIZER GRP AND Pfizer) OR (PHARMACIA ITALIA SPA PFIZER GRP AND Pfizer) OR (DRUG SAFETY EVALUAT PFIZER AND Pfizer) OR (AGOURON PHARMACEUT PFIZER AND

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(UNILEVER DISCOVER VLAARDINGEN AND Unilever) OR (UNILEVER DISCOVERY AND Unilever) OR (UNILEVER EMERY NV AND Unilever) OR (UNILEVER ENGN AND Unilever) OR (UNILEVER ENGN ENVIRONM RES LAB AND Unilever) OR (UNILEVER ENGN LONDON AND Unilever) OR (UNILEVER ENGN SERV AND Unilever) OR (UNILEVER ENV SAFETY LAB AND Unilever) OR (UNILEVER ENVIRONM SAFETY LAB AND Unilever) OR (UNILEVER ENVIRONM SCI LAB AND Unilever) OR (UNILEVER ESL AND Unilever) OR (UNILEVER EUROPE AND Unilever) OR (UNILEVER FOOD HLTH INST AND Unilever) OR (UNILEVER FOOD HLTH RES AND Unilever) OR (UNILEVER FOOD HLTH RES INST AND Unilever) OR (UNILEVER FOOD HLTH RES INST UFHRI AND Unilever) OR (UNILEVER FOOD HLTH RES INST VLAARDINGEN AND Unilever) OR (UNILEVER FOOD RES CTR AND Unilever) OR (UNILEVER FOOD RES INST AND Unilever) OR (UNILEVER FOODS AND Unilever) OR (UNILEVER FOODS AMER R D AND Unilever) OR (UNILEVER FOODS ESPANA SA AND Unilever) OR (UNILEVER FOODS HLTH RES INST AND Unilever) OR (UNILEVER FOODS NA AND Unilever) OR (UNILEVER FOODS R D AND Unilever) OR (UNILEVER FOODS RES AND Unilever) OR (UNILEVER FOODS RES CTR AND Unilever) OR (UNILEVER FORSCH AND Unilever) OR (UNILEVER FORSCH GESELL AND Unilever) OR (UNILEVER FORSCH GESELL GMBH AND Unilever) OR (UNILEVER FORSCH GESELL MBH AND Unilever) OR (UNILEVER FORSCH GESELL MBN AND Unilever) OR (UNILEVER FORSCH GESELLSCH AND Unilever) OR (UNILEVER FORSCH GESELLSCH MBH AND Unilever) OR (UNILEVER FORSCH GESELLSCHAFT MBH AND Unilever) OR (UNILEVER FORSCH GESSEL MBH AND Unilever) OR (UNILEVER FORSCH GMBH AND Unilever) OR (UNILEVER FORSCH LAB AND Unilever) OR (UNILEVER FORSCH SGESELL MBH AND Unilever) OR (UNILEVER FORSCHUNGSGESELL GMBH AND Unilever) OR (UNILEVER FORSCHUNGSGESELL MBH AND Unilever) OR (UNILEVER FORSH GESELL GMBH AND Unilever) OR (UNILEVER FORSH GESELL MBH AND Unilever) OR (UNILEVER FRANCE AND Unilever) OR (UNILEVER FS GLOBAL HR AND Unilever) OR (UNILEVER GLOBAL RES CTR AND Unilever) OR (UNILEVER GLOBAL SKIN INNOVAT CTR AND Unilever) OR (UNILEVER GLOBAL SKIN TECHNOL CTR AND Unilever) OR (UNILEVER GLOBAL SOCIAL MISSION AND Unilever) OR (UNILEVER GREECE AND Unilever) OR (UNILEVER HLTH FOOD RES INST AND Unilever) OR (UNILEVER HLTH INST AND Unilever) OR (UNILEVER HLTH INST VLAARDINGEN AND Unilever) OR (UNILEVER HLTH RES CTR AND Unilever) OR (UNILEVER HOME PERSONAL CARE AND Unilever) OR (UNILEVER HOME PERSONAL

CARE N AMER AND Unilever) OR (UNILEVER HOME PERSONAL CARE NA AND Unilever) OR (UNILEVER HOME PERSONAL CARE R D PORT SUNLIGHT AND Unilever) OR (UNILEVER HOME PERSONAL CARE R PORT SUNLIGHT AND Unilever) OR (UNILEVER HOME PERSONAL CARE USA AND Unilever) OR (UNILEVER HOUSE AND Unilever) OR (UNILEVER HPC AND Unilever) OR (UNILEVER HPC NA AND Unilever) OR (UNILEVER HPC R D AND Unilever) OR (UNILEVER HPC R D PORT SUNLIGHT AND Unilever) OR (UNILEVER HPC RES US AND Unilever) OR (UNILEVER HPC SPAIN AND Unilever) OR (UNILEVER HPC USA AND Unilever) OR (UNILEVER INST AND Unilever) OR (UNILEVER INT MANAGEMENT CONSULTANTS LTD AND Unilever) OR (UNILEVER ISRAEL AND Unilever) OR (UNILEVER ITALIA AND Unilever) OR (UNILEVER ITALY HOLDINGS SRL AND Unilever) OR (UNILEVER JAPAN KK AND Unilever) OR (UNILEVER KENYA AND Unilever) OR (UNILEVER KK AND Unilever) OR (UNILEVER KNORR FACTORY AND Unilever) OR (UNILEVER KOREA AND Unilever) OR (UNILEVER LAB AND Unilever) OR (UNILEVER LAB COLWORTH AND Unilever) OR (UNILEVER LAB RECH AND Unilever) OR (UNILEVER LIFE SCI AND Unilever) OR (UNILEVER LTD AND Unilever) OR (UNILEVER LTD UNILEVER RES AND Unilever) OR (UNILEVER MEASUREMENT SCI AND Unilever) OR (UNILEVER MED SERV AND Unilever) OR (UNILEVER MERSEYSIDE LTD AND Unilever) OR (UNILEVER N AMER AND Unilever) OR (UNILEVER N V VITALITY PROGRAMME FOODS AND Unilever) OR (UNILEVER NEDERLAND NV AND Unilever) OR (UNILEVER NUTR CTR AND Unilever) OR (UNILEVER NV AND Unilever) OR (UNILEVER NV PLC AND Unilever) OR (UNILEVER NV ROTTERDAM AND Unilever) OR (UNILEVER OCCUPAT HLTH AND Unilever) OR (UNILEVER ORAL CARE AND Unilever) OR (UNILEVER ORAL CARE RES AND Unilever) OR (UNILEVER ORAL CARE UK AND Unilever) OR (UNILEVER PERFUME COMPETENCE CTR AND Unilever) OR (UNILEVER PLANTAT AND Unilever) OR (UNILEVER PLC AND Unilever) OR (UNILEVER PORT SUNLIGHT AND Unilever) OR (UNILEVER PORT SUNLIGHT LAB AND Unilever) OR (UNILEVER PORT SUNLIGHT LABS AND Unilever) OR (UNILEVER PORT SUNLIGHT RES AND Unilever) OR (UNILEVER PORT SUNLIGHT RES LAB AND Unilever) OR (UNILEVER R COLWORTH AND Unilever) OR (UNILEVER R D AND Unilever) OR (UNILEVER R D BANGALORE AND Unilever) OR (UNILEVER R D BEBINGTON AND Unilever) OR (UNILEVER R D CHINA AND Unilever) OR (UNILEVER R D COLOWORTH AND Unilever) OR (UNILEVER R D COLWORTH AND Unilever) OR (UNILEVER R D COLWORTH HOUSE AND Unilever) OR (UNILEVER R D COLWORTH LAB AND Unilever)

OR (UNILEVER R D COLWORTH PK AND Unilever) OR (UNILEVER R D COLWORTH SAFETY ENVIRONM ASSURANCE AND Unilever) OR (UNILEVER R D COLWORTH SCI PK AND Unilever) OR (UNILEVER R D COLWORTH SCI PK SHARNBROOK AND Unilever) OR (UNILEVER R D CTR AND Unilever) OR (UNILEVER R D DISCOVER AND Unilever) OR (UNILEVER R D DISCOVER VLAARDINGEN AND Unilever) OR (UNILEVER R D FOODS AND Unilever) OR (UNILEVER R D HEILBRONN AND Unilever) OR (UNILEVER R D HPC AND Unilever) OR (UNILEVER R D INDIA AND Unilever) OR (UNILEVER R D LAB AND Unilever) OR (UNILEVER R D LAB PORT SUNLIGHT AND Unilever) OR (UNILEVER R D PORT SUNLIGHT AND Unilever) OR (UNILEVER R D PORT SUNLIGHT BIRMINGHAM AND Unilever) OR (UNILEVER R D PORT SUNLIGHT LAB AND Unilever) OR (UNILEVER R D SHANGHAI AND Unilever) OR (UNILEVER R D STRUCT MAT PROC SCI AND Unilever) OR (UNILEVER R D SUNLIGHT AND Unilever) OR (UNILEVER R D TRUMBULL AND Unilever) OR (UNILEVER R D US AND Unilever) OR (UNILEVER R D US EDGEWATER LAB AND Unilever) OR (UNILEVER R D VLAARDINGEN AND Unilever) OR (UNILEVER R D VLAARDINGEN ADV MEASUREMENT IMAGIN AND Unilever) OR (UNILEVER R D VLAARDINGEN BV AND Unilever) OR (UNILEVER R D VLAARDINGEN COE STRUCTURED EMULS AND Unilever) OR (UNILEVER R D VLAARDINGENI AND Unilever) OR (UNILEVER RANDD PORT SUNLIGHT AND Unilever) OR (UNILEVER RD COLWORTH AND Unilever) OR (UNILEVER RE AND Unilever) OR (UNILEVER RECH DEV AND Unilever) OR (UNILEVER RES AND Unilever) OR (UNILEVER RES BANGALORE LAB AND Unilever) OR (UNILEVER RES CHINA AND Unilever) OR (UNILEVER RES CO AND Unilever) OR (UNILEVER RES COLWORTH AND Unilever) OR (UNILEVER RES COLWORTH HOUSE AND Unilever) OR (UNILEVER RES COLWORTH LAB AND Unilever) OR (UNILEVER RES COLWORTH LJA AND Unilever) OR (UNILEVER RES COLWORTH WELWYN AND Unilever) OR (UNILEVER RES COLWORTH WELWYN LAB AND Unilever) OR (UNILEVER RES CORP AND Unilever) OR (UNILEVER RES CTR AND Unilever) OR (UNILEVER RES DEPT AND Unilever) OR (UNILEVER RES DEV AND Unilever) OR (UNILEVER RES DEV ADV MEASUREMENT DATA MODELIN AND Unilever) OR (UNILEVER RES DEV ADV MEASUREMENT IMAGING AND Unilever) OR (UNILEVER RES DEV BANGALORE AND Unilever) OR (UNILEVER RES DEV CHINA AND Unilever) OR (UNILEVER RES DEV COLWORTH AND Unilever) OR (UNILEVER RES DEV COLWORTH HOUSE AND Unilever) OR (UNILEVER RES DEV COLWORTH LAB AND Unilever) OR (UNILEVER RES DEV CTR AND Unilever) OR (UNILEVER RES DEV CTR SHANGHAI AND Unilever) OR

(UNILEVER RES DEV CTR VLAARDINGEN AND Unilever) OR (UNILEVER RES DEV EDGEWATER AND Unilever) OR (UNILEVER RES DEV FOODS AND Unilever) OR (UNILEVER RES DEV LAB AND Unilever) OR (UNILEVER RES DEV PORT SUNLIGHT AND Unilever) OR (UNILEVER RES DEV PORT SUNLIGHT LAB AND Unilever) OR (UNILEVER RES DEV PORT SUNLIGHT LABS AND Unilever) OR (UNILEVER RES DEV SHANGHAI AND Unilever) OR (UNILEVER RES DEV SPECT AND Unilever) OR (UNILEVER RES DEV TRUMBULL AND Unilever) OR (UNILEVER RES DEV US AND Unilever) OR (UNILEVER RES DEV VLAARDINGEN AND Unilever) OR (UNILEVER RES DEV VLAARDINGEN BV AND Unilever) OR (UNILEVER RES DEV VLAARDINGEN COLWORTH AND Unilever) OR (UNILEVER RES DIUVEN AND Unilever) OR (UNILEVER RES DIV AND Unilever) OR (UNILEVER RES DUIVEN AND Unilever) OR (UNILEVER RES DUIVEN LAB AND Unilever) OR (UNILEVER RES EDGEWATER LAB AND Unilever) OR (UNILEVER RES EDITORIAL AND Unilever) OR (UNILEVER RES EE DEV VLAARDINGEN AND Unilever) OR (UNILEVER RES ENGN AND Unilever) OR (UNILEVER RES ENGN LABS AND Unilever) OR (UNILEVER RES ENVIRONM SAFETY LAB AND Unilever) OR (UNILEVER RES ENVIRONM SAFETY LABS AND Unilever) OR (UNILEVER RES GB AND Unilever) OR (UNILEVER RES INC AND Unilever) OR (UNILEVER RES INDIA AND Unilever) OR (UNILEVER RES INDIA HINDUSTAN LEVER RES CTR AND Unilever) OR (UNILEVER RES INDIA HINDUSTAN UNILEVER RES CTR AND Unilever) OR (UNILEVER RES INST AND Unilever) OR (UNILEVER RES ISLEWORTH LAB AND Unilever) OR (UNILEVER RES LAB AND Unilever) OR (UNILEVER RES LAB COLWARTH WELWYN AND Unilever) OR (UNILEVER RES LAB COLWORTH AND Unilever) OR (UNILEVER RES LAB COLWORTH WELWYN AND Unilever) OR (UNILEVER RES LAB PORT SUNLIGHT AND Unilever) OR (UNILEVER RES LAB VLAARDINGEN AND Unilever) OR (UNILEVER RES LAB VLAARDINGEN DUIVEN AND Unilever) OR (UNILEVER RES LAB YLAARDINGEN AND Unilever) OR (UNILEVER RES LABORATORIUM VLAARDINGEN AND Unilever) OR (UNILEVER RES LABS AND Unilever) OR (UNILEVER RES LABS COLWORTH AND Unilever) OR (UNILEVER RES LABS PORT SUNLIGHT AND Unilever) OR (UNILEVER RES LABS VLAARDINGEN AND Unilever) OR (UNILEVER RES LB AND Unilever) OR (UNILEVER RES LFEGTC AND Unilever) OR (UNILEVER RES LTD AND Unilever) OR (UNILEVER RES NETHERLANDS AND Unilever) OR (UNILEVER RES PLC AND Unilever) OR (UNILEVER RES PORT AND Unilever) OR (UNILEVER RES PORT SUNLIGHT AND Unilever) OR (UNILEVER RES PORT SUNLIGHT LAB AND Unilever) OR (UNILEVER RES PORT SUNLIGHT LAB

BEBINGTON AND Unilever) OR (UNILEVER RES PORT SUNLIGHT LABS AND Unilever) OR (UNILEVER RES PORTSUNLIGHT LABS AND Unilever) OR (UNILEVER RES POST SUNLIGHT LAB AND Unilever) OR (UNILEVER RES PT SUNLIGHT LAB AND Unilever) OR (UNILEVER RES R D AND Unilever) OR (UNILEVER RES SHANGHAI AND Unilever) OR (UNILEVER RES SHARNBROOK AND Unilever) OR (UNILEVER RES SIOC AND Unilever) OR (UNILEVER RES UNITED STATES AND Unilever) OR (UNILEVER RES US AND Unilever) OR (UNILEVER RES US EDGEWATER LAB AND Unilever) OR (UNILEVER RES US INC AND Unilever) OR (UNILEVER RES US LAB AND Unilever) OR (UNILEVER RES USA AND Unilever) OR (UNILEVER RES VIAARDINGEN AND Unilever) OR (UNILEVER RES VLAAERDINGEN AND Unilever) OR (UNILEVER RES VLAARDINGEN AND Unilever) OR (UNILEVER RES VLAARDINGEN DUIVEN AND Unilever) OR (UNILEVER RES VLAARDINGEN LAB AND Unilever) OR (UNILEVER RESEARCH AND Unilever) OR (UNILEVER RESEARCH LAB AND Unilever) OR (UNILEVER RESS LAB AND Unilever) OR (UNILEVER ROTTERDAM AND Unilever) OR (UNILEVER RSCH AND Unilever) OR (UNILEVER RSCH DEV AND Unilever) OR (UNILEVER RT AND Unilever) OR (UNILEVER S AFRICA AND Unilever) OR (UNILEVER SAFETY ASSURANCE CTR AND Unilever) OR (UNILEVER SAFETY ENVIRONM ASSURANCE CTR AND Unilever) OR (UNILEVER SAFETY ENVIRONM ASSURANCE CTR SEAC AND Unilever) OR (UNILEVER SAFETY ENVIRONM SAFETY LAB AND Unilever) OR (UNILEVER SCI PK AND Unilever) OR (UNILEVER SEAC AND Unilever) OR (UNILEVER SHARNBROOK AND Unilever) OR (UNILEVER SKIN GLOBAL INNOVAT CTR AND Unilever) OR (UNILEVER SKIN R D AND Unilever) OR (UNILEVER SPAIN AND Unilever) OR (UNILEVER STAT GRP AND Unilever) OR (UNILEVER STAT SENSORY SCI GRP AND Unilever) OR (UNILEVER SUSTAINABLE AGR TEAM AND Unilever) OR (UNILEVER TEA KENYA LTD AND Unilever) OR (UNILEVER THAI HOLDINGS LTD AND Unilever) OR (UNILEVER THAI TRADING LTD AND Unilever) OR (UNILEVER TRUMBULL RES AND Unilever) OR (UNILEVER UHFRI AND Unilever) OR (UNILEVER UK AND Unilever) OR (UNILEVER UK CENT RESOURCES LTD AND Unilever) OR (UNILEVER UK HOLDINGS LTD AND Unilever) OR (UNILEVER UK LTD AND Unilever) OR (UNILEVER UNITED STATES INC AND Unilever) OR (UNILEVER VLAARDINGEN AND Unilever) OR (UNILEVERLFEDC AND Unilever) OR (UNIMILLS GMBH UNILEVER OIL MILLING DIV AND Unilever) OR (VANDENBERGH JURGENS BV UNILEVER AND Unilever))) AND **YEAR PUBLISHED:** (2010–2015)

Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI.

Web of Science Search for Dye-Sensitized Solar Cell (DSSC) Publications

DSSCs – search in WoS for 2010–2014:

TS=((Dye* or Pigment*) and (Sensiti*) and (Solar* or Photovoltaic*) and (Cell* or Batter*))

This yielded 9,748 records of various document types (primarily articles) as performed on October 13, 2015.

Table C1 shows the updated results of Big Data search in WoS dated January 27, 2016, and we extracted 11,139 records for 2010–2015 (including various document types, led by proceedings papers (5,661) and articles (4,042)).

Table C1. Search results of Big Data.

No.	Search strategy	Big Data search terms (search conducted on 1/27/2016 by Alan)	Hits – 2006–2015
1	Core lexical query	TS = ("Big Data" or Bigdata or "Map Reduce" or MapReduce or Hadoop or Hbase or Nosql or Newsql)	8,602
2	Expanded lexical query	TS = ((Big Near/1 Data or Huge Near/1 Data) or "Massive Data" or "Data Lake" or "Massive Information" or "Huge Information" or "Big Information" or "Large-scale Data" or Petabyte or Exabyte or Zettabyte or "Semi-Structured Data" or "Semistructured Data" or "Unstructured Data")	11,798
		TS = ("Cloud Comput*" or "Data Min*" or "Analytic*" or "Privacy" or "Data Manag*" or "Social Media*" or "Machine Learning" or "Social Network*" or "Security" or "Twitter*" or "Predict*" or "Stream*" or "Architect*" or "Distributed Comput*" or "Business Intelligence" or "GPU" or "Innovat*" or "GIS" or "Real-Time" or "Sensor Network*" or "Smart Grid*" or "Complex Network*" or "Genomics" or "Parallel Comput*" or "Support Vector Machine" or "SVM" or "Distributed" or "Scalab*" or "Time Serie*" or "Data Science" or "Informatics*" or "OLAP")	3,113,113 (part A AND part B = 7,696)
3	#1 OR (#2 AND #3); 2006–2016	SCI = 4,673; SSCI = 1,026, of which 541 are not also in SCI – download 541; AHCI (not in SSCI) = 45 down; CPCI-S & CPCI-SSH = 6,267 (of which 6,093 not in SCI-SSCI – download) – hit 5,000 limit, so split – download 6,093; BCI-S & BCI-SSH = 376 – download all (ignore possible overlaps) ESCI – search #1 = 0; so leave that dB out; ** save the separate downloaded into VP files in case we want to analyze sometime – note trend behavior for 2015 differs greatly from SCI/SSCI (UP) to CPCI's (DOWN). I think due largely to incomplete indexing at this date in WoS. Also saved the combo – 11,728 total – removed dups to get 11,684 (saved with the component files on the flash memory).	