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Hybrid nanomaterials research—is it *really* interdisciplinary?

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Abstract

This chapter explores whether and how the field of hybrid nanomaterials is interdisciplinary, with the aim of understanding the underlying knowledge structure of this book. To do so, we conducted a bibliometric analysis based on 113 review publications selected by the contributors. The results suggest that integration of different disciplines is carried out first, around research on specific inorganic support materials (quantum dots, carbon nanotubes, etc.), and second, around research on applications in sensing and molecular machines. The centrality of sensing applications and their pervasive presence in other clusters suggest that they constitute the key

integrative driver for interdisciplinarity in hybrid nanomaterials. The weak coherence of the field may possibly indicate that the field is in its early stages. Disciplinary diversity in hybrid nanomaterials is found to be higher than the norm in the chemistry disciplines in which it is embedded. The field draws mainly on disciplines from chemistry (Organic, Inorganic, Physical) and materials science (Multidisciplinary Materials Science, Nanotechnology, Condensed Matter, Applied Physics), as well as from some areas of biology (Biophysics, Biotechnology, Biochemistry). In summary, hybrid nanomaterials is found to be a relatively highly interdisciplinary field with knowledge integration occurring around a few specific materials and applications.

1. Introduction

One of the central tenets of the current discourse on innovation is that the most important scientific and technological breakthroughs are the result of interdisciplinary endeavours. This idea has become particularly significant in those areas of science and technology (S&T) that are perceived as being a result of technological convergence, such as nanotechnology or its cognate developments:

Revolutionary advances at the interfaces between previously separate fields of science and technology are ready to create key *NBIC transforming tools (nano-, bio, info-, and cognitive-based technologies)*, including scientific instruments, analytical methodologies, and radically new materials systems. The innovative momentum in these interdisciplinary areas must not be lost but harnessed to accelerate unification of the disciplines.

Roco and Bainbridge (2002, p. 3).

The field of hybrid organic-inorganic nanomaterials explored in this book fits nicely with this view of research as driven by applications whose development requires interdisciplinary effort. Along these lines, recent reviews have presented hybrid nanomaterials as exploiting interdisciplinary interactions between supramolecular chemistry, nanotechnology and molecular chemistry (Descalzo et al., 2006, p. 5925). However, interdisciplinarity is a rather nebulous and polysemous concept. A giant collaboration building a high energy collider is surely very different from a project on climate change in a social science institute, or a laboratory working on molecular machines. Although each of these endeavors may claim to be interdisciplinary, the underlying cognitive and social processes are markedly dissimilar.

In which sense is hybrid nanomaterials research interdisciplinary? Of the many existing perspectives on interdisciplinarity, this chapter presents an exploration of hybrid nanomaterials based on the knowledge sources of the field, using bibliometric data. The main findings are that hybrid nanomaterials research is very fragmented among different materials-centred (e.g. carbon nanotubes (CNTs) and quantum dots (QDs)), and applications-centred topics, with each of these topics drawing on disciplines from chemistry and materials sciences, and to a lesser extent the biological sciences.

The chapter is organized as follows. We begin with a ‘cautionary’ review of the current interest —and rhetoric— on interdisciplinarity in the context of the new discourses on science (Gibbons, 1999), which stress the need for science to be legitimated by producing explicit social benefits. Second, we briefly review various approaches to the assessment of interdisciplinarity and present the conceptual framework and methodology of this investigation. Third, we show and discuss the empirical results and finally, we summarize the findings.

2. The current rise of interdisciplinarity in context

Since the early 1990s there has been a boom in the (self-reported) adoption of interdisciplinarity by both scientists and policy-makers. Occurrences of the terms ‘interdisciplinary’ in scientific papers increased five-fold in 15 years, from 550 per year in 1993 to more than 3100 in 2007¹. Policy reports have highlighted the

¹ This search was carried out using ISI’s Science Citation Index database (i.e. not including the Social Sciences or Humanities) for Articles, Reviews, Notes and Letters only. Previous data are discussed in Braun and Schubert (2003).

importance of interdisciplinarity for strategic technologies such as nanotechnology (Malsch, 1997). There has been a surge in programs fostering interdisciplinary collaboration and technological convergence, such as NEST (New and Emerging Technology) in the 6th EU Framework Programme, and large investments have been made into interdisciplinary research centers, such as Cornell's Nanobiotechnology Center (NBTC).

While this enshrinement of interdisciplinarity as a positive scientific norm may today seem 'natural', we should remember that it runs contrary to the beliefs of the early 20th century:

Only by strict specialization can the scientific worker become fully conscious, for once and perhaps never again in his lifetime, that he has achieved something that will endure. A really definitive and good accomplishment is today always a specialized accomplishment. And whoever lacks the capacity to put on blinders, so to speak, ... may as well stay away from science.

Weber (1919).

Hence, this surge in interdisciplinarity needs to be put into context. Although some interdisciplinary academic and research programs were developed in the mid-20th century (Klein, 2000, p. 4), interdisciplinarity first emerged as a social and policy issue at the time of student unrest over higher education reforms in the 1960s and 1970s (Weingart, 2000, p. 25), and then regained prominence in the 1990s with the advent of a series of policy studies claiming that the science and technology system was undergoing major structural changes (see Hessels and van Lente, 2008, for a

recent review). Among these studies, the most influential is Gibbons et al.'s book (1994; see a summary in Gibbons, 1999), which depicts a transition towards a new research mode (*Mode 2*) characterized by production of knowledge in the context of application, with more transient organizational settings, wider societal considerations for the evaluation of its worth, and which includes transdisciplinary research and heterogeneity of skills among its key attributes. Other models that have focused on the stronger interaction between academia and economic or government actors, such as Leydesdorff and Etzkowitz's (1998) Triple Helix, also suggest indirectly a move towards greater interdisciplinarity in order to address societal or industrial demands.

However, the fact that this literature is prescriptive rather than descriptive suggests that "the discourse on interdisciplinarity is, in effect, a discourse on innovation in knowledge production" (Weingart, 2000, p. 30), where "interdisciplinarity provides a means for steering and coordinating strategic investment in research across a range of partners" (Lowe and Phillipson, 2006, p. 167). In other words, science is being pushed to be more interdisciplinary in order to better fulfill its new social contract, which entails a more direct interaction with societal actors via technology transfer or public engagement. In this context, the call for interdisciplinarity may become a convenient tool used to foster reform in scientific institutions (e.g. to justify the erosion of the tenure track system, see Fuller, 2003), rather than a requirement of 'organic' developments in science (as we might argue was in previously the case in areas such as biophysics).

In summary, the current discourse on science implicitly takes a prescriptive stance and believes that research 'ought' to be more interdisciplinary in order to be more

successful at dealing with societal problems and supporting innovation and competitiveness. However, since you can't get an 'ought' from an 'is', when an emergent field such as hybrid nanomaterials is presented as interdisciplinary, one cannot help but wonder: is it *really*? Or is it rather that there is an expectation (or desire?) that it become interdisciplinary?

3. The assessment of interdisciplinarity

There is an increasing consensus that the key characteristic of interdisciplinarity is knowledge integration, i.e. the combination and/or the fusion of concepts or theories, tools or techniques, and information or data from various bodies of specialized knowledge (National Academies, 2005). However, there is no agreement in the literature about how to assess the degree of interdisciplinarity (Bordons, 2004, p.453): it has been measured in a variety of ways, including the affiliations of researchers involved in collaborations (e.g. Schummer, 2004), their educational background (e.g. Sanz-Menéndez et al., 2001), the citation flows among disciplines (e.g. Porter and Chubin, 1985), and the co-occurrence of disciplines in references/citations (Porter et al., 2007) or in article headings (e.g. Tijssen, 1992).

In our view, there are three questions that need to be raised with regard the degree and type of interdisciplinarity of a field²:

- a) **How diverse and how coherent is its cognitive structure?** This question explores *which bodies of knowledge* the field is building on, and to which extent these fields are becoming integrated.

² The questions apply equally to enquire into interdisciplinarity of organizations, but for the purposes of this chapter, we will focus on fields or topics.

- b) What are the drivers of its knowledge integration?** This point aims to elucidate why the emergent field needs to pursue various knowledge sources.
- c) What are the strategies for knowledge acquisition?** This examines how laboratories garner knowledge from various disciplinary bases.

The first question looks into interdisciplinarity proper. Since interdisciplinarity is an epistemic characteristic, it has to be assessed by looking into the contents of research (e.g. examining the concepts or techniques used, or analyzing their proxies, such as the structure of publications) rather than its social practices (e.g. collaborations). The second question (*why*) enquires into the motivations for pursuing interdisciplinary research and can be investigated by looking into the attributes shared among the different bodies of knowledge that are brought together (e.g. instrumentation or application objectives). Schmidt (2007) proposed that these drivers can be epistemological (sharing theories and concepts, e.g. in complex systems studies), methodological (e.g. the atomic force microscope), ontological (i.e. objects-centered, such as carbon-nanotubes) or problem-oriented (e.g. climate change research).

Finally, the third point (*how*) looks into the social mechanisms and processes that constitute the practice of interdisciplinarity (such as recruitment, interaction within joint facilities, sharing of research material or data, etc.). Here we should like to emphasize that interdisciplinary research “does not necessarily imply collaboration between researchers from different disciplines” (Bordons et al., 2004, p. 440), and even when it does, the term ‘collaboration’ encompasses a variety of practices (Laudel, 2001, 2002). This is why in hyped fields such as nanotechnology, where the organizations and educational degrees are sometimes re-labeled without much

substantial transformation in order to cater to shifting funding demands, the number of collaborations among diverse disciplinary affiliations cannot always be assumed to be a reliable indicator of interdisciplinarity (Rafols and Meyer, 2007).

Since the aim of the present chapter is to provide a general outlook on interdisciplinarity in hybrid nanomaterials, we have focused our efforts on the knowledge structure and briefly touched upon the drivers for integration, both of which can be explored using bibliographic data. An exploration of the interdisciplinary practices (e.g. collaborations) falls beyond the scope of this investigation.

4. Data and Methods

If the boundaries between well-established research fields are always fuzzy and controversial, we have to recognize that the delineation of emergent areas of research is, inevitably, a highly arbitrary exercise. For hybrid nanomaterials, we have aimed to represent the field as characterized in this book. To do so, we asked the editor K. Rurack to provide a representative review list of the field (which comprised 28 publications), and each of the contributors to select the five most relevant review publications in the 2002-2007 period for their chapter. This yielded a total of 117 unique review publications, with only 16 overlaps (9 by the editor) among the nominated publications. 4 reviews were unused because they could not be localized in bibliometric databases. The final list of 113 reviews is presented in Appendix 1.

This set of publications allowed us to conduct a bibliometric analysis of the field, following the methodology presented in Rafols and Meyer (2009). Bibliographic

records were downloaded using data from the ISI Web of Science and processed using the bibliometric programme Bibexcel (Persson, 2008), the statistical packet R (2007), and the network analysis software Pajek (Batagelj and Mvar, 2008). We then looked into the coherence of the network obtained by linking reviews via the normalized number of shared references (bibliographic coupling). The network was divided into research topics by means of cluster analysis (SPSS 15.0 for Windows, using hierarchical clustering, with Ward's method and squared Euclidian distance). While allowing for the creation of between 5 to 15 clusters, 10 clusters were obtained, then simplified to 7 since 3 of them were tightly connected (these clusters were merged into the Hybrid Silica Materials cluster). Second, we looked at the distribution of disciplines cited in the references of reviews (where each reference is assigned to a discipline according to ISI Subject Category classification³). This distribution allowed us to assess the degree of interdisciplinarity for each cluster in terms of the number of ISI subject categories, Shannon entropy and Stirling diversity⁴. Figure 1 provides a schematic description of the methodology.

Figure 1 approximately here.

5. Knowledge structure in hybrid nanomaterials

³ The category 'Multidisciplinary sciences' was removed because it is perceived as misleading, given that its journals are multidisciplinary, but not necessarily the publications.

⁴ Let p_i be the proportion of references in discipline i , and s_{ij} the Salton's cosine similarity of disciplines i and j according to their citing patterns. Then Shannon entropy (or diversity) is defined as

$$H = -\sum_i p_i \ln p_i \text{ and Stirling diversity is defined as } \Delta = 1 - \sum_{i,j} s_{ij} p_i p_j . \text{ See Rafols and Meyer}$$

(2009) for details. Porter et al. (2007) also introduced a formulation equivalent to Stirling's diversity.

5.1 Main topics of research clusters

Figure 2 represents the knowledge structure of hybrid nanomaterials obtained from the similarity between publications in terms of shared references. For the sake of clarity, only the publications in clusters are displayed (66 out of 113, the remaining 47 publications being weakly linked), and only lines with values above 0.03 are drawn. The fact that the network is very spread, in spite of a very low similarity threshold (0.03, or about 3% shared references), indicates that hybrid nanomaterials is not (yet?) a coherent field, as one would expect from more mature areas. Cluster analysis allows us to identify groups of publications that share a certain focus as listed in Table 1. The label and description of each cluster highlights the main *specific* topic shared among the publications in the cluster. However, each of the reviews will generally also touch upon other topics (e.g. whilst all reviews on biosensing are related to gold nanoparticles, some of them also discuss QDs and CNTs for biosensing).

Table 1 approximately here

Figure 2 approximately here

The map of hybrid nanomaterials in Figure 2 not only helps us view which are the distinct research topics but also how they are related to each other. It illustrates, for example, that the cluster on coordination polymers, crystal engineering and metal-organic frameworks (top left) is very weakly related to the rest of the network. It also shows that silica hybrid materials and molecular machines are quite close to each other –which is due to the use of porous silica sol-gel to provide a stable matrix for encapsulating molecular machines in a macroscopic solid. However, since Figure 2 is a two-dimensional projection of a much higher-dimensional space, one has to be

cautious in the interpretation of apparent proximity: QD and CNT clusters appear close to each other only because they are both interconnected with the biosensing cluster, not because they are related to each other.

Perhaps the main insight to draw from Figure 2 is that hybrid nanomaterials as a field is constituted by a ‘periphery’ of research on specific support materials (QDs, CNTs, hybrid silica materials and coordination polymers), articulated around a ‘center’ focused on their applications in sensing, biosensing and, to a lesser extent, on molecular machines. This result is consistent with the general pattern that more applied research efforts (in this case in sensing) integrate more specialized areas (in this case, in inorganic support materials). It may be worth noting that the functionalization materials (biomolecules, enzymes or organic groups) do not form clusters –supporting the vision of the specific inorganic supports as generic platforms for a myriad of different organic hosts. The fact that one of the reviews contributed by the editors of this book (Descalzo et al., 2007) occupies a central position in the network is a reminder that this portrait of hybrid nanomaterials is unavoidably a partial view.

5.2 Disciplinary diversity

Whilst Figure 2 told us about the local structure of knowledge in hybrid nanomaterials, it did not explain the position of the field in the larger map of science –in terms of disciplines. In order to do this, we looked into the references contained in the review publications for the whole field and for each of the clusters. The results are listed in Table 2 and presented over a map of science in Figure 3 (see Leydesdorff and Rafols, 2009, for details of the construction of the map). Overall, the references come from

three research areas: first, from the ‘core’ chemistry areas (Multidisciplinary Chem., Analytical Chem., Organic Chem., Inorganic Chem.) in the centre of the map; second from materials science areas (Multidisciplinary Materials Sciences, Applied Physics, Nanoscience and Nanotechnology, and Condensed Matter Physics⁵) to the right of the map, as well as the chemistry areas that sit between the chemistry and materials sciences (e.g. Physical Chemistry and Polymer Science). Finally, on the left of the map, there is a small but remarkable percentage of references (above 5%) from the biological sciences (Biochemistry, Biotechnology, Biophysics and Cell Biology).

Table 2 approximately here

Figure 3 approximately here

A look into the disciplinary profile of each of the clusters helps to understand its knowledge sources and the differences and similarities between clusters. For example, Biosensing has a high percentage of references from the biological sciences (arguably due to applications), together with a relatively high proportion of Analytical Chemistry and Electrochemistry (as one expects in sensing). At the opposite extreme, Hybrid Silica Materials draws its references from Materials Science, and from Chemistry areas close to Materials Science (such as Physical Chemistry) while it has very few references to biological sciences. Figure 4 illustrates these differences using as a background the map of science.

⁵ In spite of the labels, all four of these disciplines are closely interrelated via cross-citations. Factor analysis of cross-citations shows, for example, that the loading factor of Applied Physics is 0.83 in the Materials Science dimension and only 0.25 in the Physics dimension –which is formed by more basic research subjects such as Astronomy, Nuclear Physics or Fluids and Plasmas (Leydesdorff and Rafols, 2009).

Figure 4 approximately here

The diversity of disciplines of one cluster also offers us a perspective on its degree of interdisciplinarity. Figure 5 presents the Shannon and Stirling measures of diversity for each of the clusters. The results show that Biosensing and QDs are the most interdisciplinary clusters in two respects: they both have the widest spread of references across disciplines (this is shown by the high value in Shannon's indicator), and the disciplines they cite are very varied, i.e. they draw on disparate disciplines (as shown by Stirling's high value). This is illustrated in the case of biosensing in Figure 4, with publication activity in very distant nodes: in biological sciences as well as in chemistry and materials science. Overall, from Figure 5, we can see that those with the highest diversity are Biosensing and QDs, whereas those with the lowest diversity are Coordination Polymers and Hybrid Silica Materials, which are more narrowly focused on inorganic chemistry, first, and materials sciences, second.

Figure 5 approximately here

The data presented in Figure 5 allows comparison among the diverse clusters but does not tell us whether the hybrid nanomaterials field as a whole has a high value of disciplinary diversity. To do this, we need to look at *external* benchmarks. Taking as a benchmark six review publications from the fields of Multidisciplinary Chemistry and Physical Chemistry, we obtained a Shannon diversity value of 1.5 ± 0.3 (Stirling, 0.27 ± 0.09), well below the average value in hybrid nanomaterials 2.1 ± 0.2 (Stirling, 0.44

± 0.09). This suggests that hybrid nanomaterials is indeed more interdisciplinary than the main disciplines within which it is embedded.

5.3 Drivers of knowledge integration

What is the reason *why* hybrid nanomaterials research draws on the bodies of knowledge shown in Figures 2 and 3? Or, in Schmidt's framework (see section 3), what is the type of interdisciplinarity that it is pursued in this field (epistemological, methodological, ontological, problem-oriented)? The previous mapping exercises help us explore these questions. First of all, the field is clearly not defined by shared theoretical frameworks or methods. Second, publication clustering around materials (inorganic supports) suggests object-centred interdisciplinarity in each of these clusters. This means that in the design, preparation and use of a specific support material such as QDs, there is a need to integrate knowledge from studies of its physical properties (materials sciences area), its functionalization with biomolecules or organic groups (chemistry area) and the application of QDs (e.g. as markers in biological samples). Third, the fact that the core clusters of the network are focused on sensing and that this topic is also a recurrent theme in other materials-based clusters, seems to indicate that the field of hybrid nanomaterials as a whole is articulated around applications. In Schmidt's typology, the field becomes coherent by means of problem-oriented interdisciplinarity –yet the fact that it is still very segregated into materials-based topics as opposed to applications topics reveals that it is far from mature.

6. Summary and conclusions

This chapter has explored whether and how the field of hybrid nanomaterials is interdisciplinary, with the aim of understanding the underlying knowledge structure of this book. The results of a bibliometric analysis based on 113 review publications selected by the contributors suggest that integration of different disciplines is carried out first, around research on specific inorganic support materials (QDs, CNTs, etc.), and second, around research on applications in sensing and molecular machines, as shown in Figure 2. The centrality of sensing applications and their pervasive presence in other clusters suggests that they constitute the key integrative driver for interdisciplinarity in hybrid nanomaterials. However, the fact that the cognitive structure is very scattered and that many clusters are materials-centered may indicate that the field has not yet reached maturity in terms of applications.

Regarding disciplinary sources, hybrid nanomaterials is more diverse than the norm in the chemistry disciplines in which it is embedded. As shown in Figure 3, it draws mainly on disciplines from chemistry (Organic, Inorganic, Physical) and materials science (Multidisciplinary Materials Science, Nanotechnology, Condensed Matter, Applied Physics), as well as from certain areas of biology (Biophysics, Biotechnology, Biochemistry), which provide either biomimetic ideas or arenas of application.

The chapter started by locating the current discussion on interdisciplinarity in the context of a changing science-society contract. In this context, interdisciplinarity is being supported by the funding bodies both as a means to increase social relevance and as a justification for organisational reforms. Do these generic policy drivers for interdisciplinarity apply to the field of hybrid nanomaterials? First, regarding social

relevance, the fact that sensing applications constitute the main driver for research in hybrid nanomaterials suggests that this field research is indeed striving to make technological contributions. However, as mentioned, the field appears to be in its early phases, and more driven by science-push (creating technological opportunities) than by demand-pull dynamics (searching for solutions to specific problems), which would fully comply with the social relevance rationale.

Second, the question of organizational reforms (such as creation of interdisciplinary centres) unveils the biggest limitation of the current exploration: here we have focused on cognitive mapping at the expense of looking at the type of research practices (collaboration, recruitment, etc.) by which knowledge integration is achieved in hybrid nanomaterials⁶. Anecdotal evidence suggests that, as in other nanotechnology fields, such as lab-on-a-chip, deep interdisciplinary collaborations across organizations, or intense disciplinary mixing of researchers within one laboratory, are much less common than one would expect from the discourse (Rafols, 2007). Hence further research on this other aspect, the social and organizational issues in interdisciplinary practices, is definitely needed in order to better understand the development of hybrid nanomaterials and the adequacy of the current policy frameworks.

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⁶ Research on cognitive maps (based on easily accessible databases) seemed more appropriate than looking into research practices (accessible only via extensive interviews) given the time and resource limitations, and the exploratory nature of this chapter.

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Figure captions

Figure 1. Schematic representation of the methodology employed to map the knowledge structure of hybrid nanomaterials research. See Rafols and Meyer (2009) for details.

Figure 2. Knowledge structure of hybrid nanomaterials research. The nodes of the network represent review publications. The labels indicate first author and year of publication. The lines represent the similarity between nodes, as measured by the normalized number of shared references (bibliographic coupling).

Figure 3. Disciplinary distribution in the map of science of the references in the review publications for hybrid nanomaterials. Each node represents one discipline (e.g. Organic Chemistry or Cell Biology). The node size is proportional to the number of references in a given discipline. The lines and distances portray the similarities between disciplines according to their citing patterns overall science –the more similar their citations to *all* other areas of science, the shorter and darker the lines between them. Colored labels are aggregate disciplinary areas (e.g. Physics).

Figure 4. Disciplinary distribution in the map of science of the references in the review publications for two selected clusters. Top: Biosensing. Bottom: Hybrid silica materials. See text and Figure 3 for details.

Figure 4. Measures of Shannon and Stirling diversity (in arbitrary units, a.u.) in relation to the publication disciplines of the references in the reviews. See the Data

and Methods section for their definition. Both measures are normalized dividing by the largest value in the series.

Table captions

Table 1. Description of central topics in the clusters of the knowledge structure of hybrid nanomaterials, according to bibliographic coupling networks (see Figure 2).

Table 2. Percentage of references in each discipline in the publications of a cluster topic. The shaded boxes signal the cluster with the relative highest percentage of references.

Figure 1

Figure 3

Figure 4

Figure 5

Tables

<i>Cluster</i>	<i>Description</i>
Biosensing	Use of gold supports with biomolecules and enzymes as functionalization materials, for biosensing applications (electrochemical and optical).
Quantum Dots (QDs)	Use of quantum dots, luminescence as a detection method, with organic groups and biomolecules as functionalization materials, in sensing applications.
Carbon Nanotubes (CNTs)	Use of CNTs as inorganic support, focus on electrochemistry as detection method, organic groups and biomolecules as functionalization materials, and their application in sensing.
Supramolecular Chemistry and Sensing	Use of gold and silica supports with organic groups as functionalization materials, and investigation of the mechanisms involved in host-guest chemistry, for sensing applications.
Molecular Machines	Use, for molecular machine functions, of gold and silica supports and the chemical mechanisms involved in the function (host-guest chemistry).
Hybrid Silica Materials	Use of silica with periodically mesoporous organosilicas (PMOs) morphology, with organic groups as functionalization materials, for applications in sensing.
Coordination Polymers	Use of hybrid materials composed of metal ions and organic groups (metal-organic framework based on chemical engineering) and their preparation and/or fabrication.

Table 1

Disciplines (ISI SCs)	Hyb. Nano. (ALL)	Bio- sens.	QDs	CNTs	Sup. Sens.	Mol. Mac.	Hyb. Sil.	Coor. Poly.
Chemistry, Multidiscip.	23.5	22.6	20.7	20.6	26.0	39.8	18.4	43.9
Chemistry, Phys.	21.6	11.6	16.3	17.3	27.1	8.4	31.2	13.5
Materials Sci., Multidiscip.	13.9	9.0	13.5	19.4	11.5	5.4	24.1	9.9
Chemistry, Analytical	5.3	15.7	9.1	2.4	5.4	0.6	0.8	0.0
Physics, Applied	4.4	3.8	5.2	6.3	3.6	3.2	4.4	1.4
Nanosci. & Nanotech.	3.9	7.1	4.9	9.3	3.6	3.0	3.9	0.6
Phys., Condensed Matter	3.7	2.4	4.4	3.7	3.4	2.8	4.1	2.2
Chem., Inorgan & Nucl.	2.6	0.4	0.2	0.3	0.9	4.9	0.5	20.2
Polymer Science	2.4	0.2	0.0	5.1	1.4	0.8	0.9	0.3
Electrochemistry	2.3	7.7	0.5	1.7	0.9	0.4	0.4	0.0
Phys., At., Mol. & Chem.	2.0	0.9	2.5	4.5	3.6	3.8	0.9	0.6
Biochem. & Mol. Biology	1.7	2.8	3.0	1.1	1.0	4.4	0.5	0.1
Chemistry, Organic	1.4	0.5	0.5	0.7	1.2	10.2	0.4	1.0
Biotech. & App. Microbiol.	1.0	4.4	6.7	0.4	0.5	0.3	0.1	0.1
Biophysics	1.0	3.3	1.5	0.6	0.6	1.9	0.0	0.0
Physics, Multidiscip.	0.9	0.3	0.2	0.6	1.7	2.4	0.1	0.2
Chemistry, Applied	0.8	0.0	0.0	0.1	0.5	0.0	2.8	0.7
Biochem. Res. Methods	0.8	1.6	3.0	0.7	0.6	0.3	0.1	0.0
Crystallography	0.6	0.0	0.0	0.1	0.1	1.0	0.0	4.4
Engineering, Chem.	0.5	0.0	0.0	0.2	0.7	0.0	1.4	0.2
Materials Sci., Ceramics	0.4	0.1	0.2	0.0	0.1	0.0	1.0	0.0
Cell Biology	0.4	0.4	0.5	0.1	0.0	2.8	0.1	0.0

Table 2