CAN BIBLIOMETRICS CONTRIBUTE TO THE STUDY OF INTERDISCIPLINARY INFLUENCE: A CASE STUDY OF PHYSICS

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Abstract

In this study, the mutual influencing of different fields of science is analysed by looking at the so called 'knowledge balance' between disciplines, based on the difference between numbers of reciprocal references by publications in two disciplines. A conclusion is that *Physics* and *Basic Life Sciences* appear to be important sources of inspiration for developments in other disciplines. Furthermore a method is applied, which compares the age distributions of non-disciplinary citations given to a subfield with exponential regression values. Extreme deviations from the regression lines are indicators for key papers which appear to be responsible for large interdisciplinary effects in current research. Cases in physics lead to the conjecture that large interdisciplinary impact appears to be caused more by diffusion of methods or even software and less by sudden breakthroughs.

1 Introduction

The application of citation analysis in science studies investigating the impact of a particular piece of research on subsequent research, is widespread. In analyses of the influence of research outside its own domain, bibliometrics is also widely applied in studying impact of research on innovation, among others by use of patent citation data. However, bibliometric methods have been applied more scarcely in studies of the influence of research on surrounding disciplines. Since 1980's a small number of studies on interdisciplinarity have been performed, starting with Porter et al. (Porter, 1985). Recently new applications of bibliometric indicators of interdisciplinary impact in research evaluation have appeared (National Science Board, 2000, Davidse, 1997, Kostoff, 2001, Van Raan, 2002). In most of these studies, the Science Citation Index (*SCI*), as one of few databases which spans all disciplines, is used, and the journal classification method (*JCM*) is applied for delineation of fields and subfields.

In this paper we further investigate to what degree useful information on disciplinary interactions can be obtained by citation analysis using *SCI* and *JCM*. Objections against the use of JCM (National Science Board, 2000, Rinia, 2002) are partly circumvented by our present approach.

We especially focus on the citation relations between physics and other disciplines. A leading motivation is that, although many examples of physics discoveries which were influential on other fields have been described, quantitative research on this topic is scarce. In this study, firstly, relations between different fields of science and between subfields of *Physics* and other fields are analysed by looking at the net import/export balance of citations exchanged at the level of fields and subfields.

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Secondly, in order to see what is behind these data, specific cases of cross disciplinary citing (i.e. citing publications belonging to other disciplines) are further examined. We specifically investigate examples of boosts in the number of (recent) non-physics citations to physical research results published in previous years, to see whether these are a sign of real knowledge transfer between disciplines.

2 Method

Our study is based on the papers (articles, notes, reviews, letters) included in the *SCI* on CD-ROM in 1999. We follow the method introduced by Porter et al. (Porter, 1985), which means that relations between (sub)fields are investigated by looking at the disciplinary origin of the articles cited in these papers. In particular cross-disciplinary citations, also denoted as external citations, are considered. In this study we take into account references to articles in the period 1980-1999, which are included in the SCI. Articles are classified by year of inclusion in the *SCI*.

The method to look backwards to older articles which are cited in 1999, also called the synchronous approach, was chosen, because it was preferred to consider the actual impact of previously published results, i.e. from the viewpoint of current research.

It should be noted that between disciplines there may be differences in the share of references to sources not included in the *SCI*.

Articles and references were classified, on the basis of *ISI*- journal-categories, into 15 broader disciplines. Disciplines which are distinguished are: *Basic Life Sciences; Biology; Chemistry; Clinical Life Sciences; Computer Sciences; Engineering & Technology; Environmental Sciences; Food; Agriculture & Biotechnology; Geosciences; Mathematics; Pharmacology; Physics; Psychology & Psychiatry*. Publications in multidisciplinary journals (e.g. *Nature*, *Science* or *PNAS*) are classified in this study to the 'discipline' *Multidisciplinary Science*.

In case of interdisciplinary journals (covering intersections of several subfields and assigned to more than one *ISI*-category), articles are fractionally attributed to subfields and eventually disciplines. This arithmetic attribution to (sub)fields (instead of classification by content) of articles in multiply assigned journals, is a drawback in studies of interdisciplinarity based on *JCM*. Therefore, to analyse interdisciplinary influence, in this study we introduce the concept of a *'knowledge balance'*, in analogy with the concept of *'trade balance'* applied in economics.

If science is conceived as an economic system, then 'referring to' publications of other disciplines can be considered as a sign of 'import of knowledge' developed elsewhere. Conversely, being cited by publications in other disciplines can be considered as an indication of 'export' of knowledge to these disciplines. The difference between these numbers of reciprocal references by publications in two disciplines - or between import and export of knowledge - then yields an indication of the net *'knowledge balance'* between these disciplines. Such a balance partly circumvents the objections against *JCM*, as effects of multiply assignment of journals and fractionated assignment of numbers of articles in these journals, are cancelled out and play no role in outcomes.

As with all metaphors, the parallel between the economic and scientific system is limited. For instance, the export of goods implies a more active agent than the export of knowledge - being cited. However, keeping in mind these restrictions, we think the analogy may be helpful in better understanding knowledge transfer between disciplines.

We analyse the outcomes of knowledge balances at the level of disciplines in the first part of the next section (table 1). Furthermore, knowledge balances between subfields within the discipline *Physics* and other disciplines are examined (table 2). Subfields in *Physics* are: *Acoustics; Astronomy & Astrophysics; Crystallography; Instruments & Instrumentation; Microscopy; Optics; General Physics; Applied Physics; Atomic, Molecular & Chemical Physics; Condensed Matter Physics; Physics of Fluids; Mathematical Physics; Nuclear Physics, Physics of Particles & Fields; Spectroscopy; Thermodynamics*.

In a second part, we analyse the age distributions of citations given in 1999 by other disciplines to (articles in) subfields in physics in the period 1980-1999. A comparison is made between exponential regression values and the values actually obtained. Extreme deviations are considered to be indicators of particularly relevant external impact. These deviations are separately analysed, based upon the distribution of citations to papers in the years involved. In this study we do not correct for differences in average number of references per field. Explanations for these differences, given in science studies, appear to offer no sufficient theoretical basis for such corrections. Apart from that we observed that global outcomes presented in this paper do not change significantly when weighting by the average number of references per field.

3 Knowledge balance between disciplines

Outcomes show that in scientific publications to a considerable amount is referred to research outside the own discipline. By using the classification into fifteen fields and the methods described, we find that more than one third of all references is cross disciplinary. This is a much higher share than found by Porter *et al*. (Porter, 1985), probably due to the use in our study of a much larger data set and a more refined classification of disciplines.

A conclusion about the extent of interdisciplinary knowledge transfer cannot be directly inferred from this**.** As mentioned before, partly due to methodological restrictions, a robust classification of disciplines and a rigid definition of cross disciplinary reference is hard to achieve. For a quantitative analysis of relations between disciplines, a calculation of 'knowledge balance' between disciplines is preferred, which is based on the comparison of reciprocal number of references exchanged between disciplines. A surplus on this balance shows a net export; the reverse shows that net import of references **-** knowledge **-** is taking place.

Table 1 Knowledge balance between disciplines: the difference between the number of reciprocal references by publications in two disciplines (number of references / 1000). The Net *relative* import or export expresses the Net import/export as proportion of the total number of reciprocal references in publications of two disciplines

As mentioned, in such a balance effects of multiply assigned journals and fractional attribution of numbers of articles cancel out. In the lower left part of table 1, the net import or export is expressed as percentage of the total number of reciprocal references of two disciplines. The rows give the net *relative* import of a discipline *i* , and the columns give the net *relative* export of discipline *j*.

The results show a stratification at the level of disciplines distinguished. On the one side there are some larger net exporting disciplines like, *basic life sciences* and *physics*. *Multidisciplinary sciences* (which in fact is no 'discipline') shows the largest net export. To a lesser degree also *mathematics* is a net exporter. Publications in these four disciplines appear to be a relative important source of inspiration for researchers in other disciplines.

The other disciplines show a deficit in their knowledge balance, mostly *Clinical Life Sciences*, followed by *Food, Agriculture and Biotechnology* and *Pharmacology*.

In the case of *Physics*, we find that in 1999 the total number of references from *Chemistry* to *Physics* amounts to 48000 more than the reverse: the total number of references from *Physics* to *Chemistry*. This is the result of the difference between around 130000 references from *Physics* (to *Chemistry*) and around 82000 references to *Chemistry* (by *Physics*). So, *Physics* is a net exporter to *Chemistry*. *Physics* is also a net exporter to *Materials Sciences*, *Engineering & Technology*, *Mathematics* and *Computer Sciences*. The total number of external citations to *Physics* exceeds the total number of external references by *Physics* by 68000.

Basic *Life Sciences* appears to be a large net exporting discipline too, especially because of net export to *Clinical Life Sciences*, *Food, Agriculture & Biotechnology, Biology* and *Pharmacology*.

In the case of *Multidisciplinary Sciences*, by far the largest exporting discipline, a surplus of the knowledge balance might be expected. Most likely, specific articles in *Multidisciplinary Sciences* will often be cited by, or refer to, publications which are in fact in the same discipline, but which are attributed to another discipline than *Multidisciplinary Sciences*. Consequently, a large part of these citations may not be really cross-disciplinary. Therefore, in the last two columns of table 1, net import outcomes are given in which *Multidisciplinary Sciences* is not taken into account. It appears that rankings of disciplines, according to the size of net import, hardly change when we leave references to and by *Multidisciplinary Sciences* aside: *Basic Life Sciences*, *Physics*, and *Mathematics* stay net-exporting disciplines. *Geosciences* now also shows a small net export. The other disciplines stay net importers.

The absolute size of the net import and export of especially *Basic Life Sciences* and *Clinical Life Sciences*, however, changes considerably when leaving citation relations with articles in *Multidisciplinary Sciences* aside (probably due to the large share of life science articles in *Nature*, *Science or PNAS*).

Furthermore, it appears that ranking hardly change when in stead of the absolute (right columns), the relative (bottom rows) net import is taken into consideration.

4 Knowledge balance of subfields in Physics

In the same way as at the disciplinary level, a knowledge balance can be constructed on the basis of citation relations between each subfield within a specific discipline and other disciplines. A knowledge balance between *Physics* subfields and *non-Physics* disciplines is shown in table 2.

Table 2 Knowledge balance between *Physics* subfields and other disciplines: the difference between the number references to a (non-*Physics*) discipline and the number of citations by this discipline (number of references / 100)

This table displays the difference (by hundreds) between the number of references to (articles in) a *Physics* subfield, given by a *non-Physics* discipline and the opposite, the number of references given to this discipline, by a *Physics* subfield. If the outcome is positive, then there is a net export by the *Physics* subfield concerned, else there is net import.

The import/export outcomes show which disciplines are mostly inspiring or inspired by results in subfields of physics. For instance, we find that *Chemistry* articles refer 26400 times more often to *Atomic, Molecular & Chemical Physics* than vice versa. So, *Atomic, Molecular & Chemical Physics* is a net exporting subfield to *Chemistry*, or in other words, *Chemistry* for a larger part is inspired by *Atomic, Molecular & Chemical Physics* than vice versa.

The second largest net export is by *Applied Physics* to the discipline *Materials Sciences*. About half the total net export from the discipline *Physics* to the discipline *Materials Sciences*, of about 33800 references, can be attributed to this net export by *Applied Physics*.

Applied Physics appears to be an intermediary between physics and other disciplines, referring extensively to physics papers but cited more extensively by *non-physics* papers. A result which is in agreement with other findings, for instance about the role of publications in the journal *Applied Physics Letters*, which was found to be the most cited journal in USPTO patents[5].

According to the size of total net-export (bottom row) to *non-Physics* disciplines, the subfields *Atomic, Molecular & Chemical Physics* and *Applied Physics* appear to be the largest net exporting subfields, with a knowledge balance surplus of more than 20,000 references. A third largest net exporting subfield is *Condensed Matter Physics*.

5 Case studies in physics

The calculation of a knowledge balance to investigate cross disciplinary citation flows appears to be an improvement to weaknesses of JCM for studying multidisciplinary research activity. The method yields a global view of the influence of research in one field of science on other fields. However, which research in particular plays a role in impact on other disciplines stays hidden. From case to case, though, citation analysis can be carried through in order to gain further insight in underlying developments.

As an example we take the citations given in 1999 by publications in *Chemistry* to articles in *Condensed Matter Physics.* The import/export balance in table 2 shows that in 1999 *Chemistry* articles refer about 7500 times more often to *Condensed Matter Physics* articles than vice versa. This appears to demonstrate that *Condensed Matter Physics* is an 'enabling science' for *Chemistry*. Further citation analysis was carried out to see what is at the bottom of these data.

We find that of all (19.236) references found in *Chemistry* papers to *Condensed Matter Physics*, 90% is by articles in three subfields: 12,670 by articles in *Physical Chemistry*, 1,535 by *Inorganic & Nuclear Chemistry* and 2,653 references by articles in *General Chemistry*. The age distributions of citations to *Condensed Matter Physics* by these three subfields show striking similar peaks in the number of citations to papers in 1986, 1988 and 1992 (figure 1, left). We find the same peaks in citations to *Condensed Matter Physics* by other subfields, for instance *Chemical Engineering*. In these years numbers of citations deviate significantly from values which might be expected based upon the assumption that age distributions normally show an exponential trend.

Closer examination of all cited *Condensed Matter Physics* publications published in 1986, 1988 and 1992 reveals very skewed distributions. It appears that citations to only five publications explain the peaks observed.

Figure 1 Number of citations by publications in three subfields in *Chemistry* to publications in *Condensed Matter Physics* over the period 1980-1997. Exponential trends are also shown.

If these 5 papers are left aside, the age distributions show a much closer approximation to an exponential trend (figure 1, right). In all five publications (table 4) methods are described to calculate the electron structure and - density in an electron gas. All papers were published in *Physical Review B.*

Computational methods, like the *density function theory* (*DFT*), which were developed in physics and are based upon quantum

Table 3 Numbers of references to highly cited *Condensed Matter Physics* publications in 1986,1988 and 1992 by three subfields in *Chemistry*

mechanical principles, give important information on the structure and -dynamics of molecules. In chemistry, however, these methods were not directly accepted and during some time a controversy existed between different approaches. Finally, however, it became clear that these new computational methods yield large progress in the analysis of molecules and their interactions. Nowadays, these methods are widely applied in (quantum)chemistry, biochemistry and materials sciences. A proof of the recognition of the origin in physics is the awarding of the Nobel price in chemistry in 1999 to Walter Kohn, a theoretical physicist, together with Pople.

> "Walter Kohn showed in 1964-65 that the energy of a quantum-mechanical system is uniquely determined by its electron density. This quantity is more easily handled than the complicated wave function in the Schrödinger equation. Kohn also provided a method which made it possible to set up equations whose solutions give the system's electron density and energy. This method, called density functional theory, has become widely used in chemistry since, because of its simplicity, it can be applied to fairly large molecules". (The Royal Swedish Academy of Sciences, 1998).

Citation data of the five highly cited papers by Lee and Perdew show too that this work was not immediately broadly recognised. Only after the mid 90's the numbers of citations increase enormously each year. Up till the year 2000 these five papers together were cited over 14000 times.

Table 4 Highly cited papers in *Condensed Matter Physics* in 1986,1988 and 1992

A comparison of the disciplinary origins of publications citing the two papers by Perdew, 1986 (1) and Lee , 1988 (3) in the period until 1995 and in the year 2001, also demonstrates the delayed recognition of this work in the field of *Chemistry*. In the first period, 33% of all citations to the *Perdew* paper (1) and 28 % of all citations to the *Lee* paper (3) are from publications in the discipline of *Chemistry*. In the year 2001 respectively 74% and 66% of all citations are from *Chemistry* publications.

In a second case we analysed distributions of citations to the subfield *Atomic, Molecular and Chemical Physics*. As mentioned before, this subfield is the largest net exporting subfield in *Physics*, mainly by a large net-export to *Chemistry*, more specifically to the subfields *Physical Chemistry* and *General Chemistry*. Distributions of citations by articles in several subfields in *Chemistry* to publications in

Atomic, Molecular and Chemical Physics, in the years 1985 and 1993 all show remarkable deviations from an exponential trend. Further examination learns that also in this case only a few highly cited articles play a role in citation peaks found. The share of citations to these nine papers in all citations to *Atomic, Molecular and Chemical Physics* in 1985, amounts to 21% in the subfield *Physical Chemistry*, 38% in *General Chemistry*, 73% in *Inorganic and Nuclear Chemistry* and 60% in *Organic Chemistry*. If (citations to) these nine publications in 1985 and 1993 are left aside, distributions close to a smooth curve are found.

All nine articles have been published in the *Journal of Chemical Physics*. The most cited paper among these nine is an article by A.D. Becke (Journal of Chemical Physics, Vol. 98, pg. 5648-5652, 1993) and also deals with applications of the *density functional theory* (DFT). Up till the year 2001, this paper is cited in total more than 6000 times. The other eight highly cited papers all deal with atomic and molecular electronic structure calculations and computational methods which enable chemists to predict structure, binding forces and properties of molecules much more precise than is possible by experimental approach.

The 'deviating' numbers of citations to the papers analysed, appear to be indicators of important interdisciplinary effects. Many citation histories of the top papers, found in both cases, reveal a citation life cycle classified by Cano as 'type B' (Cano, 1991), with a moderate increase of citations in an initial period but a steady take-off thereafter, up till present.

It appears that the method to compare age distributions of non-disciplinary citations with expected values, appears to finally lead us to key papers (some of which for instance have been selected as an *ISI citation classic*), which are responsible for large interdisciplinary effects in current research.

6 Conclusions

The cases analysed in the present study show that cross disciplinary citation flows reflect real effects and are indicative of research in a particular (sub)field influencing other fields of science. In studies of knowledge exchange at the level of fields and subfields in science, therefore, the analysis of cross disciplinary citations may provide useful insights. Given the limitations of the journal classification method, an appropriate focus on knowledge flows at a general level is obtained by analysing net import/export rates. More refined classification of articles in inter- and multidisciplinary journals, however, will strengthen the method.

Further citation analysis proves to be useful to analyse from case to case which research exactly is at the bottom of impact on other disciplines, as shown by global data. Cases lead to the conjecture that**,** at least in the fields of physics and chemistry in the period concerned, large direct interdisciplinary impact appears to be caused more by diffusion of methods or even software and less by key discoveries. Papers found, mainly describe advancements in the area of calculations and computational methods. Effects of breakthroughs of these methods, for instance in chemistry, appear to be large, judging by numbers of citations.

We conclude that analysis of distributions of cross disciplinary citations appear to be a useful tool for tracing contributions which have a large interdisciplinary effect. The outcomes support the conclusion that bibliometric methods to analyse interdisciplinary influence appear to be interesting, not only for retrospective analyses, but also for studying effects in contemporary research.

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Available: http://www.nobel.se/chemistry/laureates/1998/illpres/index.html

Table 1 Knowledge balance between disciplines: the difference between the number of reciprocal references by publications in two disciplines (number of references / 1000). The Net *relative* import or export expresses the Net import/export as proportion of the total number of reciprocal references in publications of two disciplines.

Right (upper)half: Net import: Ni (i,j) = ((Ri,j) - R (j,i)) / 1000
Left (lower)half: Net relative export: Nri (i,j) = ((R(i,j) - R (j,i)) /(R(i,j) + R (j,i))

Exporting discipline (j)																			
Importing discipline (i)	Basi	Biol	Chem	Clin	Comp	Engi	Envi	Food	Geo	Mate	Math	Mult	Phar	Phys	Psyc	**Import**	**Rank**	**Import excl. Multi. Sci.**	**Rank**
Basic Life Sciences		-45	-18	-169	-3	-3	-6	-52	-1	-2	0	289	-46	-2	-6	-65	***3***	-353	***1***
Biology	*21%*		-1	3	0	0	2	-9	0	0	0	25	0	0	0	64	***11***	40	***10***
Chemistry	*13%*	*6%*		-7	0	1	0	1	2	3	0	26	-5	48	0	86	***12***	60	***11***
Clinical Life Sciences	*15%*	*-9%*	*17%*		-1	-6	-3	-30	0	-2	1	122	-43	-1	-2	209	***15***	87	***12***
Computer Sciences	*39%*	*40%*	*2%*	*14%*		4	0	0	0	0	3	2	0	2	0	15	***8***	13	***8***
Engineering & Technology	*24%*	*10%*	*-4%*	*22%*	*-14%*		-1	0	-1	-2	0	2	0	8	0	9	***5***	7	***5***
Environmental Sciences	*22%*	*-3%*	*2%*	*24%*	*-24%*	*6%*		-1	2	0	0	8	0	0	0	18	***9***	11	***7***
Food, Agric. & Biotechn.	*29%*	*17%*	*-2%*	*31%*	*2%*	*-5%*	*2%*		1	0	0	16	0	0	1	109	***13***	93	***13***
Geosciences	*14%*	*1%*	*-12%*	*32%*	*1%*	*7%*	*-5%*	*-12%*		0	0	16	0	0	0	14	***7***	-3	***3***
Materials Sciences	*23%*	*12%*	*-3%*	*31%*	*11%*	*7%*	*-3%*	*1%*	*12%*		0	6	0	34	0	43	***10***	37	***9***
Mathematics	*15%*	*13%*	*-19%*	*-28%*	*-22%*	*0%*	*-21%*	*-39%*	*-17%*	*-11%*		0	0	3	0	-2	***4***	-2	***4***
Multidisciplinary Sciences	*-63%*	*-62%*	*-75%*	*-77%*	*-69%*	*-30%*	*-62%*	*-71%*	*-53%*	*-67%*	*-8%*		-18	-23	-5	-557	***1***		
Pharmacology	*24%*	*4%*	*15%*	*26%*	*2%*	*13%*	*2%*	*-3%*	*18%*	*10%*	*37%*	*77%*		0	-1	112	***14***	94	***14***
Physics	*5%*	*-4%*	*-22%*	*6%*	*-16%*	*-8%*	*-5%*	*-5%*	*-1%*	*-28%*	*-17%*	*49%*	*9%*		0	-68	***2***	-92	***2***
Psychology & Psychiatry	*9%*	*-2%*	*1%*	*7%*	*-29%*	*-24%*	*7%*	*-24%*	*-20%*	*-11%*	*13%*	*68%*	*5%*	*18%*		13	***6***	8	***6***
Export (%)	*3%*	*-14%*	*-13%*	*-12%*	*-19%*	*-3%*	*-7%*	*-24%*	*-7%*	*-15%*	*3%*	*65%*	*-24%*	*11%*	*-9%*				
Rank	***4***	***11***	***10***	***9***	***13***	***5***	***6***	***15***	***7***	***12***	***3***	***1***	***14***	***2***	***8***				
Export (%) excl. Multi. Sci.	*18%*	*-9%*	*-9%*	*-6%*	*-17%*	*-2%*	*-4%*	*-21%*	*2%*	*-13%*	*3%*		*-21%*	*16%*	*-6%*				
Rank	***1***	***9***	***10***	***7***	***12***	***5***	***6***	***14***	***4***	***11***	***3***		***13***	***2***	***8***				

Table 2 Knowledge balance between *Physics* subfields and other disciplines: the difference between the number references to a (non-*Physics*) discipline and the number of citations by this discipline (number of references / 100)

Net import: Ni (i,j) = ((Ri,j) - R (j,i)) / 100

Exporting subfield (j)																	
Importing discipline (i)	Acous.	Astro.	Cryst.	Instr.	Micro.	Optics	Phys., gen.	Phys., appl.	Phys., at,m,c.	Phys., cond.	Phys., fl & pl	Phys., math.	Phys., nucl.	Phys., part.	Spect.	Therm.	Total Physics
Basic Life Sciences	1	0	15	-2	-17	2	1	-2	9	-2	-2	-3	0	0	-19	0	-17
Biology	0	0	2	0	-1	0	1	1	0	0	0	0	0	0	-1	0	1
Chemistry	2	2	14	5	2	16	78	59	264	75	4	5	2	0	-48	0	478
Clinical Life Sciences	-2	0	-1	-2	-3	2	0	0	-1	0	0	0	0	0	-6	0	-14
Computer Sciences	1	-1	-1	-1	0	2	10	3	2	1	0	5	0	-1	0	0	19
Engineering & Technology	3	2	0	-3	-1	-1	16	39	6	18	5	2	2	-3	-2	-4	78
Environmental Sciences	0	1	0	0	0	0	0	0	0	0	1	0	0	0	-1	0	2
Food, Agricult. & Biotechn.	1	0	0	-1	0	1	0	0	1	0	0	0	0	0	-1	0	1
Geosciences	0	6	2	0	0	3	-1	1	-1	0	0	1	0	0	-6	0	4
Materials Sciences	3	0	16	3	1	12	53	157	15	81	0	-1	1	0	-5	1	338
Mathematics	1	3	0	0	0	2	12	1	0	1	1	9	1	1	0	0	30
Multidisciplinary Sciences	0	-59	-7	-3	-7	-7	-24	-34	-32	-39	-4	-7	-1	-3	-9	0	-235
Pharmacology	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	-1
Psychology & Psychiatry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total	9	-48	40	-2	-24	30	147	225	263	136	4	11	5	-7	-100	-4	
Rank	*8*	*15*	*5*	*11*	*14*	*6*	*3*	*2*	*1*	*4*	*10*	*7*	*9*	*13*	*16*	*12*	
Total excl. Multidisc. Sci	9	12	47	0	-18	37	171	259	295	174	8	18	5	-4	-91	-4	
Rank	*9*	*8*	*5*	*12*	*15*	*6*	*4*	*2*	*1*	*3*	*10*	*7*	*11*	*13*	*16*	*14*	

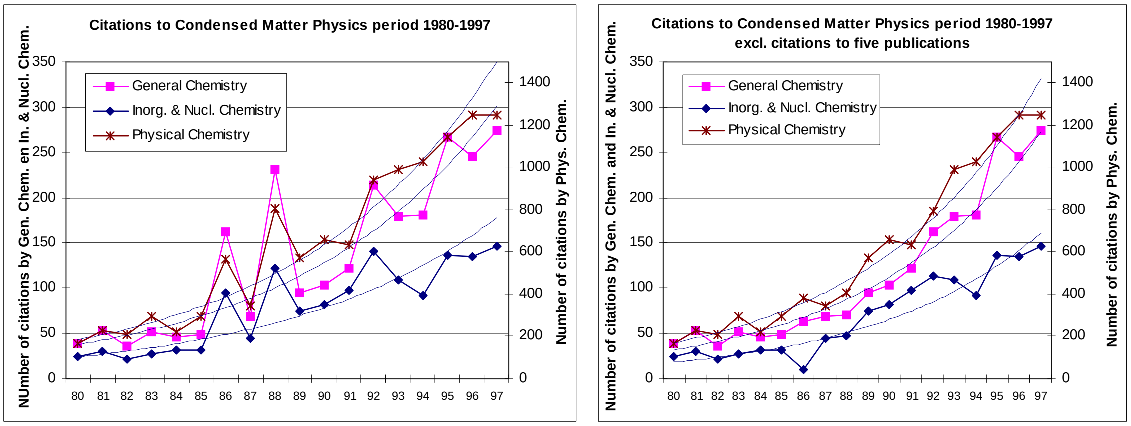

Figure 1 Number of citations by publications in three subfields in *Chemistry* to publications in *Condensed Matter Physics* over the period 1980-1997. Exponential trends are also shown.

Table 3 Numbers of references to highly cited *Condensed Matter Physics* publications in 1986,1988 and 1992 by three subfields in *Chemistry*

References in 1999	to Condensed Matter Physics publications in:					
by publications in	**1986**		**1988**		**1992**	
subfield:	total	of which to 2 publ.	total	of which to 1 publ.	total	of which to 2 publ.
Inorganic & Nucl. Chemistry	95	(85)	122	(75)	141	(28)
Physical Chemistry	566	(186)	806	(398)	939	(148)
General Chemistry	162	(99)	231	(161)	214	(52)

Table 4 Highly cited papers in *Condensed Matter Physics* in 1986,1988 and 1992

Condensed Matter Physics publications published in 1986, 1988 and 1992, which are cited most by *Chemistry* articles in 1999.

1. PERDEW JP, Density-functional approximation for the correlation-energy of the inhomogeneous electron-gas, Physical Review B-Condensed Matter, Vol. 33, Pg. 8822-8824, 1986.
   Total number of citations: 3188. Per year: 1 (1986); 7 (1987); 11 (1988); 17 (1989); 16 (1990); 36 (1991); 66 (1992); 107 (1993); 190 (1994); 221 (1995); 340 (1996); 423 (1997); 402 (1998); 468 (1999); 447 (2000); 436 (2001).

2. PERDEW JP; Correction, Physical Review B-Condensed Matter, Vol. 34, Pg. 7406-7406, 1986.
   Total number of citations: 958. Per year: 0 (1986); 0 (1987); 2 (1988); 1 (1989); 5 (1990); 15 (1991); 24 (1992); 37 (1993); 80 (1994); 78 (1995); 127 (1996); 156 (1997); 109 (1998); 98 (1999); 117 (2000); 109 (2001).

3. LEE C.T.; YANG WT.; PARR RG., Development of the Colle-Salvetti correlation-energy formula into a functional of the electron-density, Physical Review B-Condensed Matter, Vol. 37, Pg. 785-789, 1988.
   Total number of citations: 6455. Per year: 1 (1988); 4 (1989); 9 (1990); 10 (1991); 17 (1992); 37 (1993); 98 (1994); 232 (1995); 439 (1996); 705 (1997); 946 (1998); 1068 (1999); 1345 (2000); 1544 (2001).

4. PERDEW JP; WANG Y, accurate and simple analytic representation of the electron-gas correlation-energy, Physical Review B-Condensed Matter, Vol. 45, Pg. 13244-13249, 1992.
   Total number of citations: 1676. Per year: 3 (1992); 16 (1993); 40 (1994); 42 (1995); 123 (1996); 205 (1997); 275 (1998); 260 (1999); 347 (2000); 365 (2001).

5. PERDEW JP; CHEVARY JA; VOSKO SH; JACKSON KA; PEDERSON MR; SINGH DJ; FIOLHAIS C, Atoms, molecules, solids, and surfaces - applications of the generalized gradient approximation for exchange and correlation, Physical Review B-Condensed Matter, Vol. 46, Pg. 6671-6687, 1992.
   Total number of citations: 6455. Per year: 3 (1992); 38 (1993); 73 (1994); 87 (1995); 139 (1996); 205 (1997); 219 (1998); 264 (1999); 292 (2000); 400 (2001).