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Interdisciplinary and disciplinary identities: towards a theory of forms of knowledge change¹

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Abstract

The concept of interdisciplinarity lacks theoretical understanding, and consequently, the number of indicators for interdisciplinarity is booming: out of field citations, betweenness centrality, or the set coherence, diversity, mediation, to mention a few. However, these indicators focus on characteristics of papers and journals, without referring clearly to the processes of knowledge production, communication and stabilization. Without understanding of the nature of interdisciplinarity and its various forms, the choice of indicators seems rather arbitrary. In this paper we argue that interdisciplinarity is one of the forms of development of research fields. We will show that interdisciplinarity is a temporary phase in knowledge dynamics. New fields emerge at the boundaries of existing fields as multidisciplinary research activities, and either develop through an interdisciplinary phase into a 'new' discipline', or remain multidisciplinary for a while and generally disappear.

We use the analysis of journal-journal citation relations to map the identity and development of disciplinary, multidisciplinary and interdisciplinary research fields. A comparison results in three types of identities: (1) disciplinary fields, (2) interdisciplinarity as a developmental phase from multidisciplinary to disciplinary fields, and (3) unstable temporal multidisciplinary research topics at the boundaries between research fields. We conclude that the main difference between a mature interdisciplinary field and 'normal' disciplinary fields is that the former is newer than the latter. We propose to focus on change in the research landscape, instead of on indicators for what is only one (early or long term unstable) stage of interdisciplinarity. The mapping approach can be used to identify the nature of cognitive change in general, such as the emergence, growth, differentiation, merger, and decline of research fields.

Introduction

Interdisciplinary always has been an issue for discussion, and a various definitions exist, all emphasizing different degrees of interdisciplinarity. The last decade, interest has been growing as science policy makers increasingly are inclined to stimulate interdisciplinary research (refs). The idea behind this is that innovation and fundamental break-throughs occurs not in the core of existing disciplines but between them: at the intersections where different disciplines meet.²

¹ This paper was written in 2012, and is now being updated with more recent data on the developments of the fields we use as cases here: cognitive science, genomics and a few others. It is based on an approach of interdisciplinarity not as a characteristic of research fields or disciplines, but as a characteristic of the dynamics of disciplines. A first formulation is in Van den Besselaar & Heimeriks 2001, and it was applied in several case studies, among those Vugteveen et al 2014.

² A special case of this interest, of course, is 'converging technologies' (nano, bio, info, cogno) which is supposed to be the revolution of the future.

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As a consequence of this, the request for indicators of interdisciplinarity comes up, as this would improve our ability to identify (new) interdisciplinary developments. The bibliometric community has responded to this, and we see a diversity of indicators being proposed. It started with out of field citations, and now is in the stage of more sophisticated network indicators. However, also the latter are generally based on the idea of out of field citations (e.g., Porter and Rafols 2009).

In this paper I aim to further develop another perspective on interdisciplinarity, using indicators for interdisciplinarity developed quite a while ago (Van den Besselaar, Heimeriks 2001). Basically I argue that we may better change the focus from interdisciplinarity to patterns of change – and interdisciplinarity only being one of these patterns. My argument consists of the following steps:

- Firstly, I'll argue that interdisciplinarity is better conceptualized as a *position* in the scientific landscape, and not so much in terms of knowledge streams (*relations*) – although these are important too. Journal network structures do inform us about this.
- Secondly, if we look back to older interdisciplinary fields, we may learn more about the nature of interdisciplinarity than if we try to develop even more sophisticated indicators for something not very well understood. More specifically, this teaches that interdisciplinarity is a temporal stage in the development of new research fields, which either stabilize into a normal 'disciplinary' mode of communication, or remain unstable and ultimately disappear.
- Thirdly, if this is the case, we may better focus on *change* in the scientific landscape, and interdisciplinary integration is only one of the forms, next to specialization as the more general form of scientific development. But other forms of change also exist: birth of a new field, growth, decline, splitting (specialization), merging (integration), divergence, convergence and death.
- Fourthly, if these patterns of change do exist, and if the positional network structures are a correct representation, we may come up with theoretical understanding about the formal conditions under which these patterns of change occur. Sociology of science may inform us about the different social conditions for the emergence of the different patterns.

Identifying interdisciplinarity

Following Price and many others, journals can be considered as the main carrier of scholarly communication, and this is still the case in the area of electronic access.³ In a previous paper (Van den Besselaar 2001), I argued that interdisciplinarity can straightforward be studied at the level of scholarly journals – as can be done for regular research fields (e.g., Doreain & Fararo 1985; Leydesdorff & Cozzens 1993; Van den Besselaar & Leydesdorff 1996).⁴ Research fields are

³ Often it is argued that with online open access, scholars do not use journals any more for finding the material they consider relevant, but directly access articles. If this is the correct, one would expect different patterns of journal-journal citations nowadays than earlier. This does not seem to be the case, suggesting the role journals remain playing.

⁴ If journals exist, we use these for mapping the development of a field, and use papers within the determined journal set to map research fronts within the field. In case of newly emerging fields, where no dedicated journals exist yet, we use a key word based approach and identify in a second step the most prominent journals in the retrieved corpus of papers. These can be used for an initial analysis at the journal level. See: Peter van den Besselaar & Thomas Gurney 2008.

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represented as citation networks of journals. These networks have, as all communication networks, have two different structures: a positional structure and a relational structure.⁵

- Positional: journals with a similar citation behavior are clustered together: they have the same position in the network, without necessarily having strong citation relations (but often they do).
- Relational: journals with citation strong relations (mutually citing each other) are clustered together.

As already said, most indicators for interdisciplinarity take the relational network as frame of reference. The more a field cites outside its own journal set, the more interdisciplinary it is considered. However, theoretically, this is hardly convincing. If interdisciplinarity is mainly defined as theoretical and methodological integration, the use of knowledge from a different field is hardly an indicator. More explicitly, as we know, the more fundamental research fields are more cited than the application oriented ones. Both cite themselves, but the application oriented ones also heavily draw upon the fundamental ones for specific basic knowledge. That does not at all indicate that the cited fields are interdisciplinary.

In general, knowledge integration points at a different process. A field integrates knowledge from two or more fields, and therefore resembles to a certain extent these fields it integrates. Looking from the perspective of the fields that are integrated, the interdisciplinary field is to a certain extent similar, but not completely. This is captured by a positional analysis of journal-journal citation networks.

The analysis proceeds as follows.⁶ One or more core journals of the field under study are used as entrance. The citing environment of these journals is determined, and factor analyzed. Factors consist of journals with the same position in the network; that is journals with the same citing behavior. This indicates that they belong to the same research field. This is an old result which also can be used to study the dynamics of research fields over time (Van den Besselaar & Leydesdorff 1996) and for interdisciplinary fields (Van den Besselaar & Heimeriks 2001). Interdisciplinary journals are easily detected, as they load relatively high on more than one factor. This implies that they are similar to two or more research fields, an intuitively correct indicator for theoretical integration. Disciplinary research field, on the other hand, consist of journals that homogeneously load only on one factor. A third category of journals are the multidisciplinary journals, that do not aim at integrating, but that cover more than one field – but have the same factor loadings pattern as the interdisciplinary journals. Examples are of course *Science*, *Nature*, *PNAS* covering all sciences, but these journals exist also at the level of disciplines, where they cover all or several fields (like *JACS* in chemistry, or *CACM* in computer science). In the next sections I will apply this approach on different interdisciplinary fields, of different ages, in order to investigate the nature of interdisciplinarity as one form of knowledge dynamics.

⁵ These are often not clearly distinguished, resulting into wrong conclusions, e.g., on cognitive science (Goldstone & Leydesdorff 2006)

⁶ For details about the method: Van den Besselaar, Leydesdorff 1996; Van den Besselaar, Heimeriks 2001.

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Step 1: The communication structure of a traditional discipline - chemistry

Let's start with a traditional discipline and show how the journal citation network of this discipline. We use the one the main⁷ journal in the field as entrance point: *Journal of the American Chemical Association*.⁸ We determine the environment⁹ of the JACS, which consists of 44 main chemistry journals. Factor-analyzing the journal-journal citation matrix in the citing dimension result in factors containing journals with similar citing behavior. These represent the different fields within chemistry. Figure 1 shows the results. The first factor is organic chemistry. Other factors are inorganic chemistry, chemical materials, physical chemistry, biochemistry, a physics factor focusing on materials, and finally macromolecules.

FIG 1

The main journals in the various chemical subfields load on one factor only, a typical disciplinary pattern. However, we find a few quite a few journals loading on more than one factor with a substantial (>0.3) loading: the hybrid borders of the various fields. However, within these journals we have to distinguish two categories. Firstly we find the journals within chemistry that cover various chemical subfields. These are generally high impact factor journals, and colored blue in the figure. These journals are covering more chemistry fields: the broad multidisciplinary journals, often the main journals of national chemical associations, or review journals. Secondly, we find journals with loadings on more factors: the interdisciplinary journals. These journals have a "double identity" as their citation pattern is similar to more than one research field, and obviously try to integrate different bodies of knowledge. In figure 1, this holds for example for the journals on organometals, operating at the boundaries of organic chemistry, inorganic chemistry and macromolecules research. Another example in figure 1 is *Nano Letters*, spanning the boundary between chemical materials and physical materials.

Many other fields can be used to exemplify the 'normal' case. Using a dynamic perspective, the factor structure over many years can be compared. Often they are rather stable over time, as well as the set of fields they relate to, as I showed elsewhere for a series of subdisciplines within chemistry.

Please note that we excluded *Science*, *Nature* and *PNAS* from the analyses presented here, as they make the picture less clear: these journals are multidisciplinary journals in the sense that they cover all important discoveries in all fields. This gives them a different role and function.

⁷ The main journal is here defined as the (non-review) journal with the most citations in the field. We do not go for the impact factor, as size matters for impact.

⁸ The following analysis is not dependent on the choice of this journal. For chemistry as a whole, using the main journals in a variety of chemical fields for determining the journal citation network of chemistry: organic chemistry, inorganic chemistry, biochemistry, physical chemistry, chemical materials, catalysis. Although the resulting network is much bigger, this does not influence the argument made here. We also redid the analysis using one or more entrance journals of each of the fields within chemistry. This creates maps of the specific fields, which do not differ from the broad picture emerging here.

⁹ Using a threshold of 0.5%. This means we include all journals that are responsible for at least 0.5% of the citations to the JACS, and all journals that are good for at least 0.5% of the references in the JACS.

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Step 2: The communication structure of some old interdisciplinary fields

In the figure 1, an interesting observation can be made: an old interdisciplinary field, physical chemistry, actually shows a disciplinary factor structure. Most important journals load only on the physical chemistry factor itself, and only some interdisciplinary overlap exists – with chemical materials. Is this a normal pattern for established interdisciplinary fields? In order to answer the question, we now show the results for three of these old interdisciplinary fields: physical chemistry, biochemistry, and – to include also a social science example – social psychology.

Let's start with physical chemistry. The main journal in the field is the *Journal of Chemical Physics*. This leads to a citation network of 35 journals, and using factor analysis we obtain the main components. As we now started with a core journal in physical chemistry, the number of physical chemistry journals in the set is larger than in the analysis of chemistry as a whole.

As already expected from figure 1, and confirmed by figure 2, also physical chemistry has a fairly disciplinary structure: the main journals in physical chemistry have a high loading on the factor representing the field, and only in the tail of the factors we find some journals loading also on a chemistry factor with mainly general chemistry journals – that also cover physical chemistry. In other words, physical chemistry may effectively have integrated physics and chemistry – the result is a new discipline with a citation structure as other disciplinary research fields.

FIG 2

The next example is biochemistry. The main journal is the *Journal of Biological Chemistry* with a 0.5% citation environment of 35 journals. Factor analyzing the matrix shows two interesting features. There is no other chemistry field visible than biochemistry. What once started at the border between chemistry and biology now is clearly part of biology. Second, the first three factors show overlap, suggesting a similarity between biochemistry, molecular biology and molecular cell biology. This opens the question to what extent this similarity is growing or not – that may give us an indicator for process of *convergence* and *divergence* within this set of three fields. This will be done in another paper.

FIG 3

The last example of an old interdisciplinary field discussed here is social psychology. We again use the most cited journal in the field as an entrance: the *Journal of Personal and Social Psychology*. This has a citation environment of 38 journals, of which many in social psychology. Even if the field may have emerged between sociology and psychology, there is nothing left of this anymore. The field has a clear disciplinary communication structure, with most of its journals only loading on the main social psychology factor. The other factors in the environment are all psychology. So emerging in the interdisciplinary space between sociology and psychology, the field has become disciplinary and converged with psychology (and diverged from sociology).

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FIG 4

What do we learn from this analysis (Van den Besselaar, Heimeriks 2001)? Firstly, monodisciplinary fields are characterized by journals loading mainly on one factor that represents the field (e.g., the main fields within chemistry in table 1). Secondly, the journals that do load on more factors are often multidisciplinary journals covering all fields in a discipline (e.g., the general chemistry journals in table 1), or indicate the possible emergence of a multidisciplinary development (e.g., the organometallics journals in table 1). Finally, the ‘old examples’ of interdisciplinarity show that these fields in fact did become ‘disciplinary’: consisting of journals belonging one factor, that represents the field. In other words, they have a similar communication structure as the old disciplines. This is most strongly the case for social psychology, which has a very strong internal journal citation network, hardly linked to any other subfield – even within psychology. As we do not have the data to study their emergence, we now will have a closer look at some more recent examples of interdisciplinary fields, as this may teach us how this ‘disciplinary interdisciplinarity’ comes into existence.

3. The development of more recent interdisciplinary fields

Here we take up examples developed in previous publications (Van den Besselaar & Leydesdorff 1996; Van den Besselaar & Heimeriks 2001). In these papers we showed that the method introduced above can clearly be used to describe the development of research fields, and especially also for the development of interdisciplinary fields. Let’s have a look at two examples, artificial intelligence and cognitive science.

3.1 Artificial Intelligence: From interdisciplinarity to disciplinarity

An interesting type of development is seen in the case of Artificial Intelligence (AI). The field of AI started as a rather multidisciplinary field, as showed in table 5. The main journal in the field, *Artificial Intelligence Journal*, does not load on an AI factor, but is the third journal in a multidisciplinary factor with a cognitive science journal and a linguistics journal. The wider environment of *Artificial Intelligence Journal* consists of psychology, and a series of computer science related research fields.

FIG 5

However, over the years the nature of AI radically changes. More and more, over the years the *Artificial Intelligence Journal* loads on a growing factor of mainly AI and applied AI journals. Increasingly this factor dominates its own environment, being an indicator for becoming more disciplinary (Van den Besselaar 2001): The AI factor becomes more homogeneous, and the journals generally have a *disciplinary citing pattern*, which means that the journals load on one factor only. Figure 6 shows this clearly for 2007.

AI is now the first factor in the citation network, and consists of AI journals mainly. Some

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multidisciplinary journals are still present in the AI factor, such as a robotics journal that also loads on the pattern recognition factor. More specifically, the environment of *Artificial Intelligence Journal* now is heavily computer science dominated, and much of the heterogeneous nature of its citation environment in the earlier period has disappeared.

With AI, we clearly have the second pattern in its dynamics: interdisciplinary fields emerge and over time develop into a mature state. There they have stabilized a citation network that similar to the 'normal' disciplinary pattern discussed above.

FIG 6

3.2 *Cognitive science: Multidisciplinarity, failed interdisciplinarity and disappearing*

Let's move to another example: cognitive science. We analyze here the development of the journal *Cognitive Science* over the years, to inform us about the (multi)disciplinary nature of cognitive science research. Figures 7, 8 and 9 show the results of the factor analysis of the journal-journal citation matrix for the years 1988, 1998, and 2007. In the first year, we find a typical multidisciplinary pattern, with *Cognitive Science* loading lowest on two factors: cognitive psychology and artificial intelligence. This reflects the emphasis in cognitive science in those days on bridging between (and integrating) computer science (artificial intelligence) and psychology. In other words, the journal had a double identity. The larger environment of *Cognitive Science* consists of a variety of research fields within computer science and within psychology. How does cognitive science develop over the years? Ten years later, the pattern is more or less the same. The journal environment of *Cognitive Science* has become larger, but *Cognitive Science* is still in the tail of cognitive psychology and of computer science.

Again ten years later, in 2007, the picture has changed. *Cognitive Science* has a radically changed environment, as computer science related fields have become less central, and *Cognitive Science* has become part of the cognitive psychology factor. One may say that it has lost its computer science and artificial intelligence identity, and has been normalized within psychology. There is still knowledge exchange between computer science and cognitive science/psychology (not analyzed here), but the cognitive distance has become larger. In other words, the multidisciplinary interface between psychology and computer science, as embodied in journals like *Cognitive Science*, has disappeared.

These results provide us with the third model, emerging of multidisciplinary, unstable development and disappearance.

FIG 7, 8, 9

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However, a new research field has emerged in the environment of cognitive science / cognitive psychology, which is brain and neuroscience. As a test, we mapped the citation environment of a core journal of the newly emerged factor on brain and neuroscience: the *Journal of Cognitive Neuroscience*. The results are in figure 10. Interestingly, new multidisciplinary activities have developed, but now at the interface of cognitive neuropsychology and brain science, facilitated by new imaging technologies. The *Journal of Cognitive Neuroscience* is a main multi-identity journal that spans these boundaries.

FIG 10

4. The development of recent forms of interdisciplinarity

Does the approach also work for more recent fields? Here we try for genomics and for nanotechnology.

4.1 Genomics

We start with a list of the 23 main genomics journals, provided by Antoine Schoen (Paris-Est, IPTS). We determined the citation environment of the journals in 2007 and in 2000 (for those that already existed in 2000). In the following two figures we visualize the factor structure of genomics for the two years. The lines indicate the similarity between the journals (the nodes) in terms of citation behavior (so not: citation relations).

In 2000, the genomics journals were mainly in a factor with protein research and with bioinformatics. One of the genomics journals (*Genome*) loaded on the food research factor. Between 2000 and 2008 the genomics field did grow, but it also differentiated. In 2008 we therefore see quite a few factors with genomics journals. In other words, genomics is not a (inter)disciplinary research field, but it has differentiated into a series of fields applying genomics in existing research: (1) proteomics, (2) food genomics, (3) plant genomics, (4) human genomics, (5) genomics in cancer research, and (6) pharmacogenomics.

FIG 11, 12

4.2 Nanoscience

The opposite development is visible in nanoscience, that emerged within chemical materials, applied physics, and in bionanoscience. However, using a journal-journal citation approach, a latent underlying factor becomes visible over the years consisting of most nanoscience journals. This suggests that nanoscience merges in to a new research field with a 'normal' disciplinary communication (citation) pattern. At the same time, nanotech application in biomedicine and electronics are visible in other parts of the knowledge landscape.

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ADD figures

5. Conclusions

We started the analysis with investigating the disciplinary journal citation network as a base line. As shown, disciplinary fields have a clear structure in of the journal-journal citation relations: the journals representing the disciplinary field under study all load on one single factor that represents the field.

In contrast to this disciplinary journal citation network, we distinguish a multidisciplinary one, which consists of journals with multiple identities: journals belonging to more research fields, and therefore loading on more than one factor – factors representing the fields the multidisciplinary journals relates to. As easy to understand (and as the factor loadings indicate), these multidisciplinary journals are not in the core of the fields, but more at the boundaries. Indeed, innovation within science happens at the boundaries between existing research fields and disciplines.

Using this finding, we could proceed in clarifying interdisciplinarity. Interdisciplinary fields, as we illustrated using of Artificial Intelligence as an example, are new developments emerging between fields, which over time stabilize and transform into ‘normal’ and ‘disciplinary’ research fields with similar citation structures/patterns as traditional disciplinary fields. In other words, there is no significant difference between disciplinary and *mature* interdisciplinary fields. Therefore, the focus on *change* in the journal citation networks is be more meaningful than discussions about *nature* interdisciplinary research – as it changes during its development. Change may mean a variety of things, such as emerging new fields, growth, differentiation, merging, decline, and disappearance. Elsewhere we will generalize this approach of interdisciplinary to knowledge dynamics in general (Van den Besselaar, Schoen et al – in preparation).

Of course, innovation may fail, and early multidisciplinary developments may not successfully develop into a new (first interdisciplinary and then new disciplinary) field. The example of cognitive science clearly indicates this. It continued to have an unstable position in the scholarly landscape, and more recently it was ‘absorbed’ by cognitive psychology.

Of course, one would like to understand under which conditions stabilization happens, and under which conditions it does not. And, are these conditions cognitive (the field is appealing enough to attract researchers; no competing fields emerge elsewhere), or social (funding for example, or the establishment of scholarly associations or of institutionalizing a field as a university program)? We cannot discuss this in depth here, but a few observations can start the process of understanding.

Firstly, the Artificial Intelligence case showed not only differentiation into a stable field, but also a relatively strong growth of the field. From year to year, more journals entered the field. Also, the field is in a stable way dominated by acknowledged core journals. In contrast, the cognitive science case is completely different. The field did not grow as interdisciplinary endeavor, but remained small between two growing related environments: (i) on the one hand the strongly growing field of disciplinary cognitive psychology, and (ii) the emerging AI field on the other. This may have reduced the cognitive space, hindering cognitive science to become a new interdisciplinary development. And more recently, a third competing field came up between cognitive psychology and biology: cognitive neuroscience came up. This all reduced the space for cognitive development, and the journal with

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that name remained therefore for several decades an isolated driving force. And obviously, without growth there is no possibility of stabilization of a new field.

If interdisciplinarity is a process – as we argued in this paper - the search and development of indicators for interdisciplinarity seems to be completely on the wrong track. More precisely, in the different phases of its development, interdisciplinarity has different characteristics. Indicators for should reflect this, and unfortunately, existing indicators do not do so.

Take for example the proposed interdisciplinarity indicator of *betweenness centrality* (Leydesdorff 2007)¹⁰. The idea is that the higher betweenness centrality, the more interdisciplinary a journal is. In the light of our results, this is a clear mistake as it actually only holds for early interdisciplinarity. The more the field grows and stabilized – that is, the more it is successful – the lower betweenness centrality will become. Consequently, high betweenness does not say anything about interdisciplinarity, if we do not know whether the field is in an early or late stage. The same holds for other indicators that recently have become popular recently, such as coherence and diversity (Rafols & Meyer 2010). Also these indicators have values related to the phase of development the interdisciplinary field is in. Interdisciplinary success here means actually increasing disciplinarity.

Quantitative indicators for interdisciplinarity should therefore measure at least three things: (i) the age and phase of a new field, partly indicated by growth or lack of it; (ii) the level of multidisciplinary the of the involved journals, that is the structure of the citation network of the field under study, and (iii) the relations with other fields in the environment. With a set of indicators like this, we are able to identify interdisciplinary forms of knowledge dynamics, but also other forms.

Summarizing, interdisciplinarity should be considered as a specific form knowledge dynamics, and not as a characteristic of a journal or field.

¹⁰ The ‘betweenness centrality’ indicator is also confusing two other reasons. (i) Betweenness centrality is a *relational* concept that refers to centrality in bridging communication. But it is used for a *positional* phenomenon, identifying similar positions in the citation network. A good example where it goes wrong is an analysis of cognitive science (Goldstone and Leydesdorff 2006), where the authors confuse the relational role of the journal *Cognitive Science* with its position in the citation network. (ii) The indicator is used as if the citation network is unvalued, as it translates a valued network (journals as nodes, correlations as links) into an unvalued one, by introducing a threshold.

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Fig 1 J Am Chem Soc (2007)

	Org chem	Inorg chem	Chem mater	Phys chem	Biochem	Physics	Macro molec
Synlett	,982						
Eur j org chem	,976						
Tetrahedron	,970						
Tetrahedron lett	,965						
Synthesis-stuttgart	,963						
J org chem	,958						
Org lett	,941						
Org biomol chem	,916						
Adv synth catal	,899	,311					
J mol catal a-chem	,720						
Chem rev	,846	,362	,313				
B chem soc jpn	,680	,489	,380				
Chem commun	,670	,544	,438				
Chem-eur j	,661	,569	,332				
Accounts chem res	,634	,494	,479				
Angew chem int edit	,633	,446	,365				
J am chem soc	,601	,482	,453				
Dalton t		,956					
Eur j inorg chem		,954					
Inorg chim acta		,940					
Inorg chem		,919					
Polyhedron		,911					
J organomet chem	,366	,755					,363
Organometallics	,352	,724					,380
Cryst growth des		,707	,502				
J mater chem			,884				
Chem mater			,882				
Adv mater			,869				
J phys chem c			,709	,493			
Langmuir			,694				,345
J phys chem a				,961			
Phys chem chem phys				,956			
Chem phys lett				,953			
J chem phys				,927			
J phys chem b			,485	,774			
Biochemistry-us					,952		
J mol biol					,936		
J biol chem					,889		
Phys rev lett						,918	
Phys rev b						,910	
Nano lett			,602			,647	
Macromolecules			,302				,778

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Figure 2: The factor structure of the Journal of *Chemical Physics*

	Physical chemistry	chemistry	physics cond mater	pnas s & n	physics stat mech	Macro molecules
theor chem acc	0.98					
mol phys	0.97					
int rev phys chem	0.97					
j chem phys	0.96					
chem phys	0.95					
j chem theory comput	0.94					
int j quantum chem	0.94					
annu rev phys chem	0.93					
phys chem chem phys	0.93					
chem phys lett	0.92					
j phys chem a	0.91					
j mol struc-theochem	0.89	0.38				
j comput chem	0.88	0.36				
chemphyschem	0.77	0.48				0.30
j mol struct	0.61	0.50				
j mol spectrosc	0.57					
j phys chem b	0.56	0.39				0.51
chem-eur j		0.93				
j am chem soc		0.90				
inorg chem		0.87				
chem rev	0.43	0.78		0.30		
j phys-condens mat			0.93			
phys rev b			0.93			
surf sci			0.82			
phys rev lett			0.68		0.66	
j non-cryst solids			0.57			
p natl acad sci usa				0.93		
science				0.90		
nature				0.89		
biophys j				0.65		
phys rev a					0.95	
j phys b-at mol opt					0.93	
phys rev e			0.34		0.62	
langmuir						0.80
macromolecules						0.67

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Fig 3: Journal of Biological Chemistry

	Biochemistry	Cell biology	Gene / mol cell biol	neurosci	Immunology hematology	Microbiology	Virology
FEBS J	.917						
BIOCHEM J	.913						
J BIOL CHEM	.871	.340					
MOL PHARMACOL	.867						
FEBS LETT	.864						
CELL SIGNAL	.851	.349					
BIOCHEM BIOPH RES CO	.828		.320				
BIOCHEMISTRY-US	.808						.338
METHOD ENZYMOL	.755	.351	.424				
CURR PHARM DESIGN	.665				.470		
J MOL BIOL	.654						.499
ENDOCRINOLOGY	.564						
J CELL BIOL		.909					
MOL BIOL CELL	.397	.876					
J CELL SCI	.496	.821					
NAT CELL BIOL		.786	.510				
GENE DEV		.473	.785				
ONCOGENE	.474		.719				
MOL CELL	.388	.444	.705				
MOL CELL BIOL	.477	.447	.667				
CELL		.529	.643	.313			
CANCER RES	.397		.630		.349		
EMBO J	.504	.559	.563				
NUCLEIC ACIDS RES	.405		.527				.454
J NEUROSCI				.964			
NEURON				.945			
J NEUROCHEM	.578			.684			
J IMMUNOL					.837		
BLOOD					.712		
J CLIN INVEST	.402				.698		
J BACTERIOL						.971	
MOL MICROBIOL						.941	
J VIROL							.606

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Figure 4: Citation environment of the *Journal of Personal and Social Psychology*

	soc psy	abnorm psychol	appl psy	cons psy	dev psy
pers soc psychol b	.950				
j pers soc psychol	.945				
group process interg	.943				
self identity	.943				
pers soc psychol rev	.941				
j exp soc psychol	.938				
eur j soc psychol	.934				
adv exp soc psychol	.933				
basic appl soc psych	.931				
psychol inq	.910				
j pers	.904				
pers relationship	.893				
j res pers	.892	.305			
motiv emotion	.865	.359			
brit j soc psychol	.862				
j soc pers relat	.853				
annu rev psychol	.848				.331
eur j personality	.840	.312			
soc cognition	.838				
j soc clin psychol	.832	.405			
j appl soc psychol	.751		.493		
organ behav hum dec	.744		.496		
cognition emotion	.698	.523			
emotion	.689	.517			
psychol sci	.597				.581
sex roles	.533				
pers indiv differ	.491	.482			
am psychol	.322				
j abnorm psychol		.814			
psychol bull	.391	.812			.355
behav res ther		.768			
j appl psychol			.889		
acad manage rev			.755		
j consum res				.823	
j consum psychol	.493			.725	
psychol rev					.768
child dev				-.302	.608

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Figure 5: Artificial Intelligence (1982)

	Computer sci	Pattern anal	Cognitive sci	Electrical eng	Hci	Psychology
Communic acm	,865				,399	
Lec notes comp sc	,862					
Journal acm	,811					
Comput surv	,778		,417			
Computer	,753	,501			,322	
Tsi_t	,702				,685	
Ieee t pattern anal	,118	,913				
Comput image graph	,189	,812				
Ieee t man syst cyb		,713				
Cogn_sci			,941			
J pragmatics			,764			
Artif intell	,175		,749			
P_ieee				,949		
P soc photo-opt inst				,940		
Int j man-mach st					,859	
J exp psychol human						,831
Psychol bull						,748

Figure 6: Artificial Intelligence (2007)

	Artif Intel	Intell systems	Theor comp	Pattern rec	Mach learn	Comput Sci	Econometrics
Artif intell	,929						
J artif intell res	,917						
Ai commun	,917						
Int j artif intell t	,845				,309		
Ai mag	,807						
Appl artif intell	,777		,409				
Ieee int conf robot	,766			,384			
Comput intell	,723		,375				
Proc int c tools art	,626			,392	,499		
Lect notes artif int	,625	,411			,374	,433	
Adv soft comp		,970					
Int j intell syst		,969					
Fuzzy set syst		,953					
Int j approx reason		,915					
Dynam cont dis ser b		,748		,610			
Inform sciences		,714					
Expert syst appl		,554					
Theor comput sci			,962				
J acm			,937				
J logic comput	,610		,743				
Ann math artif intel	,685		,686				
Ieee t syst man cy c	,363		,623	,432			
P soc photo-opt ins				,947			
Pattern recogn				,945			
Ieee t syst man cy b		,567		,624			
J mach learn res					,940		
Mach learn					,921		
Lect notes comput sc				,404		,827	
Acm t comput log	,541					,780	
Econometrica							,994
Game econ behav							,994

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Figure 7: Cognitive science (1988)

	Cogn Psy	Science PNAS	Artif Intel	Child devel	Educ Psy	Psy	Psy	Comp sci	Neural networks	Semiotics
J mem lang	,925									
J exp psychol learn	,876									
Psychol rev	,824									
Cognitive psychol	,804			,364						
Science		,941								
P natl acad sci usa		,926								
Ai_mag			,916							
Artif intell			,908							
Int j man mach stud			,543							
Cognitive sci	,331		,482							
Cognitive dev				,947						
Child dev				,940						
Cognition	,425			,455			,335			
Educ psychol					,934					
J educ psychol					,896					
Instr sci					,681					
Psychol aging						,867				
Psychol bull						,848				
New ideas psychol							,844			
Behav brain sci		,323				,323	,746			
Commun acm								,879		
Lect notes comput sc								,846		
Ieee t syst man cyb									,924	
Neural networks		,669							,678	
Semiotica										,914

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Figure 8: Cognitive science (1998)

	Cogn Psy	Comp sci	Educ Psy	Scienc e	Neurla comp	6	7	8	9	10	11	12	13
J exp psychol learn	,943												
Mem cognition	,935												
Cognitive psychol	,930												
J exp psychol gen	,922												
J mem lang	,895												
Psychol rev	,881												
Lang cognitive proc	,776								,301				
Cognition	,710					,460							
Psychol bull	,703						,537						
J exp psychol human	,702												
Cognitive sci	,499	,355						,304	,486				
Comput intell		,978											
Lect notes artif int		,975											
Artif intell		,968											
J exp theor artif in		,938											
Int j hum-comput st		,909											
User model user-adap		,859											
Lect notes comput sc		,821			,450								
Comput linguist		,722							,508				
Mind mach	,332	,601											
Contemp educ psychol			,974										
J educ psychol			,960										
Educ psychol rev			,936										
Z padagog psychol			,813				,321						
Cognition instruct			,656						,556				
Science				,884									
Behav brain sci	,305			,828									
Network-comp neural				,762	,365								
Ieee t neural networ					,954								
Neural networks					,930								
Cognitive dev						,899							
Child dev						,782	,466						
Am psychol							,782						
Subst use misuse							,771						
Behav inform technol								,847					
Ergonomics								,753					
Hum-comput interact	,409							,665					
Language									,762				
Int j sci educ										,779			
J learn sci										,602		,462	
Brain lang											,736		
Behav res meth ins c											,693		
J am med inform assn											-,328		
Acad med												,832	
J radiol													,919

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Figure 9: Cognitive Science (2007)

	Cogn Psy	Brain Res	Psy	Educ Psy	Dev psy	Comp sci	HCI	Learning	Brain langu	Sci educ
Q j exp psychol	,940									
J exp psychol learn	,933									
Psychon b rev	,932									
Mem cognition	,901									
J exp psychol gen	,845		,448							
Psychol rev	,831									
Cognitive psychol	,827				,317					
J mem lang	,786								,356	
Cognitive sci	,739									
Cognition	,629				,560					
J exp psychol human	,626									
Cogn syst res	,616									
Cereb cortex		,880								
Trends cogn sci		,825								
Aip conf p		,770								
J cognitive neurosci		,730							,411	
Behav brain sci		,724	,304							
Brain res		,657								
Neurocomputing		,634								
J pers soc psychol			,920							
Psychol sci	,391		,754							
Psychol bull	,352	,413	,734							
Am j psychol	,513		,731							
Psychol learn motiv	,493		,676							
Think reasoning	,452		,479							
Contemp educ psychol				,977						
Educ psychol rev				,972						
J educ psychol				,959						
Learn instr				,881						
Developmental sci					,845					
Dev psychol					,774					
J child lang					,650					
Interact stud			,326		,633	,438				
Lect notes artif int						,949				
Artif intell						,916				
Lect notes comput sc		,569				,741				
Mind mach						,475				
Comput hum behav							,658			
Int j hum-comput st							,649			
J learn sci								,844		
Etd-educ tech res				,322				,726		
Brain lang									,817	
Int j sci educ										,813

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Fig 9b: 2008

Cognitive science also loads on a factor representing philosophy of psychology

Fig 3: the citation network of cognitive science in 2008

	cogn. psy.	interdisci.	dev. psy.	Vision Percept.	cogn. neurosci.	instructio.	perceptio.	filos. psy.	comput. educ.	hci	math. psy.	acoust. pragmatics
j exp. psychol. learn.	,965											
j mem. lang.	,950											
mem. cognition	,944											
psychon. b. rev.	,926											
q. j. exp. psychol.	,917											
j exp. psychol. gen.	,897											
cognitive psychol.	,842											
lang. cognitive proc.	,796											
psychol. rev.	,747										,425	
acta psychol.	,729						,494					
Cognition	,651		,366					,490				
cognitive sci.	,646							,479				
j exp. psychol.-appl.	,555									,555		
behav. res. methods	,547											
discourse process	,539						-,380				-,319	
psychol. sci.	,535	,319										
appl. cognitive psych.	,525							-,309				-,329
cogn. syst. res.	,518							,411				
IEEE J. conn.		,958										
Nature		,942										
Science		,938										
lect. notes. artif. int.		,923										
philos. t. r. soc. b.		,920										
p. natl. acad. sci. usa		,916										
lect. notes. comput. sc.		,906										
dev. psychol.			,971									
child. dev.			,963									
j exp. child. psychol.			,926									
developmental sci.			,923									
j child. lang.			,593									
j vision				,952								
vision. res.				,944								
Perception				,825								
j cognitive neurosci.					,921							
NeuroImage					,881							
neuropsychologia					,879							
trends cogn. sci.		,529			,492			,332				
brain. res.		,521			,380							
instr. sci.						,867			-,339			
educ. psychol.-us			,450			,748						
phys. rev. spec. top.-ph.						,703						
etrd. educ. tech. res.						,700			-,353			
percept. psychophys.	,353			,481			,713					
music. percept.							,670					
j exp. psychol. human	,565			,387			,649					
philos. psychol.		,496	,331					,701				
behav. brain. sci.		,674						,484				
comput. educ.									-,727			
comput. hum. behav.									-,716			
hum. factors										,814		
int. j. hum.-comput. st.										,739		
j math. psychol.	,328										,776	
j acoust. soc. am.												,733
j pragmatics												,368

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Table 10. *Journal of cognitive neuroscience* (2006) - 8 factor solution

	Neuro- Science	Cogn Neuro Psychol	Cognitive psychology	Science/ Nature	Brain research	Human brain mapping	Psycho- physiol	Percep- tion
J neurosci	.977							
Curr opin neurobiol	.959							
Trends neurosci	.959							
Annu rev neurosci	.946							
Nat neurosci	.939							
Eur j neurosci	.916							
Neuron	.906							
Nat rev neurosci	.900			.366				
Cereb cortex	.860					.357		
Neuroscience	.820				.455			
J physiol-paris	.791			.349				
J neurophysiol	.761							
Brain res	.712				.540			
Neuroreport	.698				.332	.437		
Neurosci biobehav r	.682				.483			
Neurosci lett	.671				.578			
Trends cogn sci	.627			.336		.361		
Neuropsychology		.906						
J int neuropsych soc		.902						
Cortex		.856						
Brain cognition		.825				.352		
Neuropsychologia		.824				.375		
Cogn neuropsychol		.675						
Brain lang		.598						
Brain		.593			.436			
Neurology		.445			.419			
J exp psychol gen			.923					
J exp psychol learn			.922					
Mem cognition			.897					
J mem lang			.874					
Psychol rev			.786					
Psychol sci			.681					.334
Cognition			.558	.329				
Lect notes comput sc	.313			.896				
Science				.862				
P natl acad sci usa	.379			.862				
Nature	.300			.835				
Ann ny acad sci	.359			.806				
Prog brain res	.506				.692			
Brain res bull	.598				.690			
Exp brain res	.336				.500			.478
Clin neurophysiol					.466		.428	
Hum brain mapp						.897		
Neuroimage						.880		
J cognitive neurosci	.332	.513				.672		
Cogn affect behav ne	.511	.380				.569		
Psychophysiology							.956	
Boil psycho							.949	
Int j psychophysiol							.917	
Percept psychophys			.372					.766
Vision res								.687
J exp psychol human			.603					.664

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Figure 11: genomics 2000

Fig 12: Genomics research (2007)