Unidad de Políticas Comparadas (CSIC)
Working Paper 01-04

Interdisciplinarity as a multidimensional concept: Its measure in three different research areas

Luis Sanz-Menéndez

Unidad de Políticas Comparadas (SPRITTE-Spanish Policy Research in Innovation & Technology, Training & Education). Consejo Superior de Investigaciones Científicas (CSIC). Alfonso XII 18, 28014 Madrid (Spain). lsanz@iesam.csic.es

María Bordons

Centro de Información y Documentación Científica (CINDOC). Consejo Superior de Investigaciones Científicas (CSIC). Joaquín Costa 22, 28002 Madrid (Spain). mbordons@cindoc.csic.es

M. Angeles Zulueta

Universidad de Alcalá, Facultad de Documentación. San Cirilo s/n, 28801 Alcalá de Henares (Spain). ma.zulueta@uah.es

January 2001

Interdisciplinarity as a multidimensional concept: Its measure in three different research areas

Luis Sanz-Menéndez[1], María Bordons[2] and M. Angeles Zulueta[3]

[1]*Unidad de Políticas Comparadas* (*SPRITTE-Spanish Policy Research in Innovation & Technology, Training & Education*). Consejo Superior de Investigaciones Científicas (CSIC). Alfonso XII 18, 28014 Madrid (Spain). lsanz@iesam.csic.es

[2]*Centro de Información y Documentación Científica (CINDOC).* Consejo Superior de Investigaciones Científicas (CSIC). Joaquín Costa 22, 28002 Madrid (Spain). mbordons@cindoc.csic.es

[3]Universidad de Alcalá, Facultad de Documentación. San Cirilo s/n, 28801 Alcalá de Henares (Spain). ma.zulueta@uah.es

Abstract

Interdisciplinarity is analyzed in three different research areas: Pharmacology & Pharmacy, Cardiovascular System and Materials Science, by means of data collected from a survey to Spanish scientists. The study focuses on three different and complementary dimensions. First, diversity in personal training and research specialization of scientists is analyzed both in the field and within the research teams. Secondly, research practices and behavior of the groups are considered, taking into account the use of cross-disciplinary knowledge or techniques and the collaboration with scientists from other disciplines. The third dimension refers to the cognitive inputs and outputs of the research activity and focuses on the diversity of subjects of the journals used for publication and for reference by the research teams. Interdisciplinarity emerges in research areas as a double edge process: either as a process of jumping into a new area with people of different disciplines, in coherence with the traditional disciplinary research teams, or as a process of specialization in field traditionally dominated by a single group of disciplinary backgrounds, in which researchers from different areas join the research teams. Thus specialization-fragmentation-hybridization come all-together.

1. Introduction

Interdisciplinary research has become the new talisman in European science policy discourse. *The Green Paper on innovation* (EC, 1995), the 5th Framework RTD Programme (EC,1998) and even the last communication from the Commission on *The European Research Area* (EC, 2000), have all attributed a very significant role to interdisciplinary research. Traditionally, “disciplinary" knowledge production approaches dominated Research Councils and funding agencies strategies in the sixties and seventies (Rip, 1994). However in the last two decades we have witnessed a significant evolution in the policy discourse, first towards “strategic research" but nowadays the focus is more on “solving societal problems” (Elzinga & Jamison, 1995; Caracostas & Muldur, 1998; Sanz-Menéndez & Borras, 2001). The new policy discourse on science presents interdisciplinary research as *good*, *desirable* and *inevitable*. Scientists also agree with the positive effects that interdisciplinarity may create in the knowledge production process[1].

Sociology of science traditionally has described the process and the conditions of knowledge growth as either the “promotion of disciplinary differentiation” (Storer & Parsons, 1968), “segmentation and differentiation processes” (Hagstrom, 1965), or as a “model of branching” (Mulkay, 1975) when referring to the proliferation of new problem areas and the development of new disciplines. However, it also has been found that “cross-fertilization of fields” (Crane, 1972), or “boundary crossing” (Gyerin, 1983, 1995;) play a significant role in new knowledge production. More recently, it has been stated that the reconfiguration of knowledge takes place within a “specialization-fragmentation-hybridization process” (Dogan & Phare, 1990). In addition, social scientists have detected major changes in the way knowledge is produced. A “new Mode 2” (Gibbons *et al*.,1994) is emerging in contrast with the traditional knowledge generated mainly in disciplinary contexts dominated by cognitive concerns. The new Mode 2 operates within a context in which problems are not set by disciplinary approaches but rather within a broader transdisciplinary social and economic setting.

Thus, the issue of interdisciplinary research appears to be very relevant in both policy and analytical terms. In this context we have witnessed new attempts to describe and measure interdisciplinarity. From scientometrics and information science most of the focus has been on the information transfer process studying either “borrowing” or importing theories or methods from other disciplines (White & McCain, 1989), "collaboration" between authors from different disciplines (Gibbons et al, 1994) or “boundary crossing” (Davis, 1992; Pierce, 1999; Small, 1999). In the attempts to measure, scholars go from case studies of interdisciplinary groups (Younglove-Webb *et al,* 1999) or even interdisciplinary research centers (Palmer, 1999), towards bibliometric approaches that seek to analyze the whole production of a country (Katz & Hicks, 1995). Using publication data interdisciplinarity has been studied by “citation patterns” (Porter & Chubin, 1985; Tomov & Mutafov, 1996; Hayashi & Fujigaki, 1999), by “disciplinary/cross-disciplinary publications in collaboration” (Bourke & Butler, 1998; Hinze, 1999), by ”co-citation” (Small, 1999) and by “co-word analysis” (Tijssen, 1992).

In our previous studies, attempts of measuring interdisciplinarity were made through bibliometric indicators (Bordons *et al* 1999; Zulueta & Bordons, 1999; Morillo *et al*, 2001). As a result, we are aware of the main problems that bibliometric approaches face, such as the use of arbitrary delimitation of disciplines for classificatory purposes. On the other hand, it is clear that bibliometric indicators only monitor one of the possible dimensions of interdisciplinarity: that reflected in journals through the scientific communication practices. Since interdisciplinarity is a multidimensional concept, which refers not only to the knowledge practices but also to the structures and behavior of the research groups, we believe that a combined use of bibliometrics with more traditional sociological tools, such as survey techniques, more adequately provides a comprehensive insight into the problem.

What we will present here is an exploratory exercise of measuring the degree of interdisciplinarity in three different research areas (Pharmacology & Pharmacy, Cardiovascular System and Materials Science), according to the data provided by a sample of surveyed researchers. In this paper we present partial results from a survey designed to measure some of the dimensions and features of interdisciplinarity implemented in the three research areas mentioned. We start, in the next section, with a summary of methodological characteristics and a description of the basic features of the survey. We follow in section 3 with a detailed presentation of our results of comparing the research areas using the different dimensions identified. We conclude with a discussion of insights and the general conclusions emerging from our data.

2. Methodology

This study focuses on three different research areas: a) Pharmacology & Pharmacy, as a sample of a basic biomedical research area; b) Cardiovascular System, as a clinical biomedical area; and c) Materials Science, as an applied and technological area. A specific questionnaire was developed for measuring interdisciplinarity in the three selected research areas. The following section describes the dimensions of the interdisciplinarity concept and the indicators that make its measurement operational.

2.1. Dimensions and indicators of interdisciplinary

Conceptual differences between the terms "multidisciplinarity" and "interdisciplinarity" can be pointed out: "multidisciplinarity" refers to the grouping of researchers/results from different disciplines, and "interdisciplinarity" can be understood as being a further step forward towards the integration of disciplines. From this point of view, we could refer to "multidisciplinary teams", composed of researchers from different disciplines, and to "interdisciplinary work", as the result of the work of a multidisciplinary team, in which the integration is supposed. However, since we recognize that both terms are very interrelated, the term "interdisciplinarity" is used in this paper in a broad sense to cover all possible uses and situations.

The first dimension for the study of interdisciplinarity is related to the structure and composition of the different research areas. We have identified educational training of researchers, considered either as individuals or as members of research groups. This dimension can be explored at different levels of analysis. Aggregating individual data we can describe the different areas according to the educational training diversity of its researchers. Moreover, data on the research group composition can be used to determine the extent to which there is a dominance of disciplinary groups or interdisciplinary ones in the different areas.

For the study of this first dimension, research team composition, was monitored through: a) interviewees' qualitative appreciation of the degree of interdisciplinarity of their teams; b) disciplinary diversity of team members. The interviewees were requested to list up to five of their colleagues, including their discipline and specialization areas. We have considered as “disciplines” the main areas of knowledge included in the Spanish academic curricula, such as Medicine, Biology or Chemistry. The “specialization” corresponded to more specific subjects, such as Molecular Biology or Inorganic Chemistry.

The second dimension considered in this analysis refers to the behavior of researchers while developing their own activities. The previous dimension attempted to associate interdisciplinarity with some structural features, but this dimension is a dynamic one, in such as it refers more to practices developed by teams that could give better insights on the emergence of interdisciplinarity. The specific indicators for this second dimension included: a) use of knowledge and techniques from other disciplines; b) consideration of interdisciplinarity as selection criteria for the incorporation of new members to the team; c) external research collaboration with groups or scientists from other disciplines.

The third dimension refers to the cognitive inputs and especially outputs of the research activity, since researchers are well aware of adoption and diffusion of concepts from and to other areas. Here we have developed an analysis that is much more traditional in line with bibliometric explorations, for example, looking at the journals used for publication or as references within the different research fields, and thus determining variation as a symbol of interdisciplinarity. Specifically, subject categories of journals, following the Science Citation Index (SCI) classification of journals into categories, were identified for both: a) publication journals and b) reference journals.

2.2. The Survey as a data source

A survey was conducted using a questionnaire that included 43 questions in four different sections: a) socio-professional features of the individual researcher, b) cognitive context of reference, c) team features (including internal collaboration within the team) and d) external collaboration (beyond one's team). Although individual scientists answered the questionnaire, the research group was considered our basic unit of analysis.

Our target sample of interviewees were selected by two methods: a) principal researchers in Spanish public funded research projects in each of the three areas analyzed over a three year-period (1995-1997); and b) very productive authors of papers in the Science Citation Index (SCI) journals in each of the three areas studied over a four-year period (1994-97).

The questionnaires were sent to a total of 1032 scientists, considering the relative size of each of the research areas in Spain distributed in the following way: 310 scientists in the Cardiovascular System area (CARD), 348 in Pharmacology & Pharmacy (PHARM) and 374 in Materials Science (MATER). In the overall sample 43% of the interviewed were principal researchers, 42% highly productive authors in SCI publications, and 15% shared both features. The overall response was 65%, which is good considering it was a mailed questionnaire.

The distribution of responses by geographical regions and institutional sector of origin, in each of the three analyzed areas, shows a pattern quite similar to the general distribution of the scientific production of Spain in each of the areas. Around 70% of the scientists from Cardiovascular System belong to Hospitals; while University is the most common institutional affiliation of researchers in Pharmacology and Materials Science. We believe these data support that our sample and respondents are representative of the Spanish population of scientists in each of the areas[2].

3. Results: Comparing interdisciplinarity in three research areas

3.1. General features of the respondents

A starting point in our research was the idea that most of the dimensions of interdisciplinarity should be more associated with the collective form of research development based on groups rather than on the individual research activities. Under this assumption, most of the questions in the survey were addressed to the "team", instead of to the "individual researcher". In this context, the incidence of teamwork among the respondents becomes a variable to be controlled. The data are presented in table 1.

Table 1. Distribution of the respondents by research arrangements

	CARD	**PHARM**	**MATER**	**TOTAL**
Working in a group				
Institutionalized unit	27.5%	38.1%	43.7%	37.2%
Non-institutionalized unit	59.3%	54.3%	53.9%	55.6%
Working alone	13.2%	7.6%	2.4%	7.2%
Total valid answers (*n*=)	189	223	254	666

We found that more than 93% of the total respondents said that they developed their research as a part of a research team. It is interesting to note that in all the three areas the dominant arrangement of collective research was a group that did not correspond to an institutionalized unit. However, for the purposes of this paper, all types of groups were considered, whether they were institutionalized or not.

3.2. Interdisciplinary features

What follows are the results of the comparison between the research areas using the dimensions and indicators of our study.

3.2.1. Dimension 1: Homogeneity and diversity in the disciplinary composition of research areas and research groups

3.2.1.a. Academic degrees of researchers

Using the information on the academic degrees[3] provided by the interviewees about themselves, we determined the degree of diversity or homogeneity of the field, comparing the dominant disciplines in which the researchers have been trained.

Table 2. Principal academic degrees of researchers interviewed by discipline

	CARD (n=190)	**PHARM** (n=224)	**MATER** (n=256)
Ph.D.	161 (85.0%)	196 (87.5%)	248 (96.9%)
	Medicine..........83.8% Biology...............8.7% Pharmacy..........5.6% Chemistry..........2.5%	Medicine ....46.4% Pharmacy..........27.0% Chemistry ....19.4% Biology 6.1%	Chemistry.......50.0% Physics.......... 37.5% Engineering... 10.0%

Observing the Ph.D. degrees of respondents (table 2), the internal diversity of the three areas was analyzed. CARD shows the highest homogeneity in academic degrees of its researchers, since around 84% of CARD scientists have a Ph.D. in Medicine. In PHARM and MATER the distribution is less unbalanced. PHARM research area is also dominated by scientists with a Ph.D. in Medicine (46.6%), but followed by researchers with a degree in Pharmacy (27%) and Chemistry (19%); while in the case of MATER, the most frequent Ph.D. is Chemistry (50%), followed by Physics (37%) and Engineering (10%).

At individual level very few scientists showed interdisciplinary scientific training as measured through having several degrees in different subject areas. Although interdisciplinarity can hardly be detected looking at the scientific trajectory of scientists at the individual level, the analysis of the academic degrees of the researchers provides us an interesting picture of the interdisciplinary composition of the whole area.

3.2.1.b. Disciplinary composition of research teams

In the questionnaire the degree of interdisciplinarity of research team composition was analyzed through two complementary questions.

First, respondents had to assess the general disciplinary/interdisciplinary composition of his/her team by selecting one out of four predefined categories of which two at least could be considered clearly multidisciplinary teams (see table 3). Most of the interviewees described their own research groups as composed by researchers from the "same discipline and other disciplines and specializations". Around 63% of the researchers from CARD described their own research groups as "multidisciplinary"[4], while for PHARM it was 60% and for MATER only 43%.

Table 3. Disciplinary composition of research teams according to interviewees' opinions

The team is composed by persons from:	**CARD**	**PHARM**	**MATER**	**TOTAL**
1. Same discipline and same specializations	20.1%	27.3%	31.0%	26.9%
2. Same discipline and different specializations	16.4%	12.6%	25.7%	18.9%
3. Same discipline and other disciplines and specializations	54.1%	52.5%	38.0%	47.9%
4. Other disciplines than mine	9.4%	7.6%	5.3%	7.1%
Valid answers (n=)	*159*	*198*	*245*	*602*

Second, the interviewee was requested to list up to five of his/her colleagues from the research group, describing their disciplines and specializations. This question was answered in 86% of the total surveys, but five names with five areas and disciplines were provided only in 45% of the respondents.

We registered the number of different disciplines and specializations present in each group; these were analyzed separately. Collaboration between scientists from different disciplines (for example, medicine and biology) can be considered as interdisciplinary. We thought that in addition, collaboration between authors with different specializations involved a certain degree of interdisciplinarity due to the type of definitions adopted by disciplines. For these reasons the two variables were studied. Most of the teams included only members from one discipline and one area of specialization. In fact, around 41% of PHARM teams, 45% of CARD teams and 58% of the MATER ones included only members from the same discipline. A higher diversity was found in relation to scientist specializations, 28 % of CARD, 38% of PHARM and 42% of MATER teams included only members from the same specialization.

Table 4 shows the number of different disciplines and specializations per team in each of the three areas analyzed. It is clear that larger teams are more likely to show more disciplines in their composition. The discipline diversity for each team is calculated as the ratio between the number of different disciplines within a group and the total number of disciplines provided. This index is intended to normalize diversity in relation to group size.

Table 4 Interdisciplinary composition of teams

	CARD (n=125)	**PHARM** (n=132)	**MATER** (n=203)	Significance
No. Different disciplines/team	1.84±0.89 Med=2 (1-5)	1.83±0.79 Med=2 (1-4)	1.58±0.8 Med=1 (1-5)	P<0.001*
No. Different specializations/team	2.51±1.16 Med=2 (1-5)	2.28±1.13 Med=2 (1-5)	2.06±1.07 Med=2 (1-5)	P<0.01**
Discipline diversity	0.48±0.24 Med=0.4 (0.2-1)	0.50±0.24 Med=0.5 (0.2-1)	0.41±0.19 Med=0.4 (0.2-1)	P<0.01*
Specialization diversity	0.60±0.23 Med=0.6 (0.2-1)	0.57±0.26 Med=0.5 (0.2-1)	0.53±0.26 Med=0.5 (0.2-1)	P<0.05**

Note: values expressed as average ± standard deviation; Med=median; Range= (minimum-maximum).
*Significant differences between CARD and MATER, PHARM and MATER
** Significant differences between CARD and MATER

Again the lowest interdisciplinarity, this time measured through the number of diverse disciplines and specializations in the research groups, appears in the MATER teams. They show not only the lowest number of different disciplines but also the lowest diversity.

The most frequent discipline present in CARD groups was Medicine, in 87% of the teams, followed by Biology, in 36% of the CARD groups. In PHARM and MATER groups the dominance of a single discipline was less relevant. In PHARM, 58% of the groups had one or more members from Medicine, while Pharmacy was present in 37% of the groups and Chemistry in 34% of them. In MATER the disciplines most frequently present were Chemistry and Physics, in 62% and 52% of the teams respectively, but its interesting to note that “Materials Sciences”, considered as a discipline, was also present in around 8% of the groups.

Finally, to define the patterns of disciplinary composition of the research teams in the three different areas and to observe the interaction between the different disciplines in the research groups, we have differentiated between groups composed by researchers from the same discipline and groups in which there is more than one discipline. The results are presented in table 5.

Table 5. Presence of disciplines in single and multi-disciplinary teams

Disciplines	**CARD**		**PHARM**		**MATER**	
	Type of research groups (single /multiple disciplines)					
	% single	**% multiple**	**% single**	**% multiple**	**% single**	**% multiple**
Medicine	66.4	33.6	48.8	51.2		
Biology	21.2	78.8	7.9	92.1		
Pharmacy	7.7	92.3	24.5	75.5		
Chemistry			54.0	46.0	43.5	56.5
Physics					40.0	60.0
Engineering					14.6	85.4
Geology					18.2	81.8
Mater. Science					70.6	29.4
Others	0.0	100.0	0.0	100.0	0.0	100.0
Valid answers (n=)	143		145		221	

Around 57% of PHARM teams were composed by researchers sharing the same discipline. Most of the multidisciplinary teams combined scientists from Medicine, Pharmacy, Biology and Chemistry.

Around half of the PHARM teams including researchers from Medicine or Chemistry had also another discipline in the group, thus indicating a multidisciplinary composition. Researchers with pharmaceutical or biological backgrounds have a higher tendency to be involved in multidisciplinary teams, in 75% and 92% of the cases respectively.

Around 66 % of the CARD teams were composed by members all from a single discipline. The most frequent combination in multidisciplinary CARD teams was Medicine and Biology (representing 67% of multidisciplinary teams). Biology as a discipline was mostly integrated in multidisciplinary teams (78.8%)

Around 57% of the MATER teams were single disciplinary, especially from Chemistry and Physics . The most frequent combination of disciplines was Physics and Chemistry (14% of all teams). MATER is an area that represents a merger of researchers from Chemistry, Physics and Engineering that are present in the 62%, 52% and 22% of all research teams respectively. It is interesting to note that around 40% of the teams in Physics and Chemistry are single-disciplinary, while most of the Engineers are involved in multidisciplinary teams (85%).

3.2.2. Dimension 2: Interdisciplinary behavioral patterns of researchers

3.2.2.a. Use of knowledge and techniques from other disciplines

A “cognitive” dimension could also be used as a criterion for labeling interdisciplinarity. We have defined an empirical measure of the knowledge use and borrowing by asking the respondents about the “use of knowledge and techniques from other disciplines or fields”. There is an amazing level of interdisciplinarity, because 88% of MATER groups, 84% of PHARM and 82% of CARD teams said that they used knowledge and techniques from other disciplines.

If we compare with previous measures of interdisciplinarity, beyond the multiple or single discipline composition of the research teams, notably what emerges is the fact that most researchers acknowledge that they use knowledge and techniques from other disciplines. At the same time this answer probably reflects a more self contained idea of respondents about their own discipline in comparison with our operational definition of discipline, as educational training.

3.2.2.b. Dominant criteria for incorporation of new members

Trying to understand strategic aspects of the interdisciplinary phenomena we also asked the researchers about other issues considered as behavioral attitudes in relation to interdisciplinarity. Researchers were requested to choose between four types of criteria used when selecting or incorporating new members to their research teams. To “sustain the disciplinary homogeneity of the research group” was the dominant criteria for incorporation of new members in PHARM and MATER (in around 40% of the teams), followed by “trend towards complementing group abilities” (38-39%). In CARD, “to complement the research group with specialists of other disciplines” was the most frequent criteria expressed (35%), followed by the "maintenance of the research group homogeneity" (33%).

However, around 18% of the research teams in CARD selected as a first criteria “the diversification of the type of research with the incorporation of new researchers from other areas”, while in the cases of PHARM and MATER this criteria had only been selected in less than 10% of the cases. It seems that the attitude in relation to the interdisciplinarity is explicitly intentional and much more open in the case of CARD than in the other research areas.

3.2.2.c. Group involvement in external scientific collaboration

A common measure of interdisciplinarity is the practice of collaboration of the research teams. One way of dealing with the cognitive needs of research groups is the development of collaboration with other individuals or groups, which could be either from the same or from a different discipline. That is, collaboration could be taken either as a way to complement the disciplinary competencies of the research team with other disciplines (leading to interdisciplinarity) or as a way to reinforce the disciplinary capabilities through redundancy (which may guaranty a bigger disciplinary impact).

MATER research teams were the most collaborative ones as we can observe in table 6, where 20% indicated that they always collaborate. Only 1% of the MATER teams, 8% of the PHARM and 12% of the CARD teams said they did not collaborate at all.

Table 6. Group involvement in external collaboration

	CARD	PHARM	MATER	TOTAL
Always external collaboration	6.8%	7.8%	20.5%	12.5%
Frequent external collaboration	59.3%	61.5%	73.4%	65.5%
Rare external collaboration	21.6%	14.2%	5.3%	12.7%
Not collaboration at all	12.3%	8.3%	0.8%	6.4%
Valid answers (n=)	162	218	244	624

Table 7. Disciplinary/Interdisciplinary orientation of external research collaboration

	CARD	PHARM	MATER	TOTAL
Extreme disciplinary	32.1%	20.3%	30.0%	27.4%
Moderate disciplinary	17.5%	21.5%	18.3%	19.2%
Balance disciplinary/interdisciplinary	15.3%	20.3%	16.5%	17.5%
Moderate interdisciplinary	13.1%	18.1%	17.4%	16.6%
Extreme interdisciplinary	21.9%	19.8%	17.8%	19.3%
Valid answers (n=)	137	177	230	544

As we already have mentioned collaboration does not always imply interdisciplinary behavior. When we identify the discipline of the collaborators, in Table 7, collaboration was highly interdisciplinary in 18% of MATER teams, 20% of PHARM teams and 22% of the CARD teams. With respect to the incidence of interdisciplinary collaboration, CARD and MATER show a quite similar behavior, while PHARM appears as the area more oriented towards interdisciplinary collaboration. Only 20% of PHARM teams show extreme disciplinary collaboration vs. 32% of CARD and 30 % of MATER teams.

3.2.3. Dimension 3: Journals (for reference and publication) as inputs and outputs

3.2.3.a. What journals to read, and in which journals to publish?

Bibliometric measures were also used to measure interdisciplinarity. Interviewees were requested to indicate the titles of the five most important journals in which they have published and the titles of the five most important journals in their fields, that is, their main reference journals.

In table 8 we have the ranking of the response rate for both publication and reference journals for the research groups in each field. We clearly observe that *Circulation* is by far the most relevant journal for publication (57.1%) and reference (34.2%) in the area of CARD. In PHARM the *British Journal of Pharmacology* was the most important publication and reference journal, but less significantly than in the previous case 19% and 17%, respectively. In MATER the journals mentioned are less clearly established, because *Physical Review B* appears in the first place as a publication journal (16.4%), while for the reference journals *Macromolecules* (14.9%) and *Physical Review Letters* (14.1%) rank the highest.

Table 8. Main publication and reference journals mentioned by interviewees

CARDIOVASCULAR SYSTEM					
Publication Journals			**Reference Journals**		
Rank	Title	Response* (%)	Rank	Title	Response* (%)
1	CIRCULATION	34.21	1	CIRCULATION	57.14
2	J AM COLL CARDIOL	18.42	2	NEW ENGL J MED	35.16
3	HYPERTENSION	14.47	3	J AM COLL CARDIOL	25.82
4	ATHEROSCLEROSIS	12.50	4	LANCET	21.43
5	EUR HEART J	12.50	5	CIRC RES	18.68
6	AM J CARDIOL	11.84	6	ARTERIOSCL THROMB VASC	14.84
7	REV ESP CARDIOL	11.84	7	HYPERTENSION	14.84
8	LANCET	9.87	8	J HYPERTENS	12.64
9	ARTERIOSCL THROMB VASC	9.21	9	J CLIN INVEST	10.44
10	MEDICINA CLÍNICA	9.21	10	EUR HEART J	9.89
Valid responses n=152			Valid responses n=182		

PHARMACOLOGY & PHARMACY					
Publication Journals			**Reference Journals**		
Rank	Title	Response* (%)	Rank	Title	Response* (%)
1	BR J PHARMACOL	19.00	1	BR J PHARMACOL	16.98
2	EUR J PHARMACOL	15.00	2	NATURE	10.38
3	J MED CHEM	8.50	3	SCIENCE	10.38
4	INT J PHARM	8.00	4	PHARM RES	9.91
5	LIFE SCI	8.00	5	J PHARM SCI	9.43
6	ANTIMICROB AGENTS CH	7.50	6	J PHARMACOL EXP THER	9.43
7	J ORG CHEM	7.00	7	EUR J PHARMACOL	8.96
8	J PHARM SCI	7.00	8	ANTIMICROB AGENTS CH	8.02
9	J PHARMACOL EXP THER	7.00	9	J MED CHEM	8.02
10	BRAIN RES	6.50	10	J ORG CHEM	8.02
Valid responses n=200			Valid responses n=212		

MATERIALS SCIENCE					
Publication Journals			**Reference Journals**		
Rank	Title	Response* (%)	Rank	Title	Response* (%)
1	PHYS REV B	16.39	1	MACROMOLECULES	14.86
2	APPL PHYS LETT	13.11	2	PHYS REV LETT	14.46
3	MACROMOLECULES	13.11	3	ADV MATER	14.06
4	J APPL PHYS	12.30	4	APPL PHYS LETT	13.65
5	POLYMER	11.89	5	PHYS REV B	12.45
6	ADV MATER	11.48	6	J APPL PHYS	12.05
7	J PHYS CHEM-US	11.48	7	CHEM MATER	10.84
8	PHYS REV LETT	11.48	8	J AM CHEM SOC	10.04
9	CHEM MATER	10.66	9	POLYMER	10.04
10	J AM CHEM SOC	9.43	10	ACTA MATER	8.84
Valid responses n=244			Valid responses n=249		

* Refers to the valid responses (% of groups that have mentioned the journal)

3.2.3.b. Number of Different SCI areas of publication and reference journals

Overall the response rate was good (see table 9), around 80% of CARD scientists, 90% of PHARM scientists and 95% of the MATER scientists responded with at least one publication. The average responses were 2-3 journals, but the distribution of responses was very skewed -as shown in Table 8-. In any case, a higher average number of responses per journal for reference than for publication journals can be observed, at least in CARD and PHARM. It is interesting to note that more than 80% of the publication and reference journals cited are included in the Institute for Scientific Information databases. Spanish journals were cited more frequently as publication than as reference journals, although the data reflects a significant degree of “internationalization” of the Spanish publication of research in the three areas studied.

With the aim of studying the relation between disciplines, publication and reference journals mentioned by the respondents were distributed according to their subject categories, following the SCI classification of journals into categories (ISI). The main categories of the journals cited are shown in the last row of the Table 9. It is interesting to note that in each area only 30-35% of the responses referred to journals classified in their own field following the SCI categories. Almost all the same categories appear highest ranked for both reference and publication journals lists. A higher concentration of responses is observed for reference than for publication journals as reflected in the areas PHARM and CARD.

Table 9. Journals of Reference and Publication. Main features.

	CARD		PHARM		MATER	
	Publication Journals	*Reference Journals*	*Publication Journals*	*Reference Journals*	*Publication Journals*	*Reference Journals*
% Answers % Full-Answers (5 journals).	80% 50%	95% 80%	90% 70%	95% 80%	95% 80%	98% 75%
No. Journal mentions	655	712	931	1004	1154	1155
No. Different journals mentioned	206	145	357	330	304	302
No. Mentions/journal (average)	3.2	4.9	2.6	3.0	3.8	3.8
No. SCI Journal mentions	601 (91.76%)	685 (96.21%)	887 (95.27%)	976 (97.21%)	1076(93.24%)	1010(87.45%)
No. Different SCI Journals mentioned	170 (82.52%)	129 (88.97%)	321 (89.91%)	305 (92.42%)	244 (80.26%)	220 (72.85%)
No. Spanish Journal mentions	61 (9.31%)	24 (3.37%)	27 (2.9%)	13 (1.29%)	9(0.78%)	9(0.78%)
No. Different Spanish Journals mentioned	17 (8.25%)	9 (6.21%)	12(3.36%)	6 (1.82%)	6(1.98%)	6(1.99%)
No. AREA Journal mentions	201(30.69%)	238 (33.43%)	330 (35.45%)	335 (33.37%)	355 (30.74%)	355 (30.76%)
No. Different AREA Journals	36 (17.48%)	23 (15.86%)	73 (20.45%)	61 (17.09%)	66 (21.71%)	71 (23.51%)
No. Different SCI Categories	49	40	77	74	66	66
Principal SCI categories of the journals mentioned	CARD 31.0% PERI 24.9% HEMA 15.3% INTMED 10.8%	PERI 34.6% CARD 33.4% HEMA 24.6% INTMED 19.0%	PHAR 35.4% BIOC 13.8% NEUR 10.1% CHEM 6.4% CHEMED 6.3% INTMED 5.0%	PHAR 33.4% BIOC 12.7% NEUR 9.8% CHEM 7.1% CHEMED 6.0% INTMED 5.8%	MAT SCI 22.7% CHEM PHY 16.2% POLYM 12.5% APPLIED PHY 9.8% SOL ST.PHYS 9.3% METALL 7.8%	MAT SCI 22.2% CHEM PHY 14.8% POLYM 12.3% APPLIED PHY 9.5% SOL ST.PHYS 8.0% METALL 7.9%

Abbreviations. CARD= Cardiovascular System. PERI= Peripheral Vascular Diseases. HEMA=Hematology. INTMED=Internal Medicine, PHAR= Pharmacology. BIOC=Biochemistry. NEUR=Neurology. CHEM= Chemistry. CHEMED=Medical Chemistry. MAT SCI=Materials Science. CHEM PHY= Physical Chemistry. POLYM= Polymers. APPLIED PHY= Applied Physics; SOL.ST.PHYS= Solid State Physics. METALL=Metallurgy.

"AREA journal" refers to a) Pharmacology & Pharmacy journals in PHARM; b) Cardiovascular System journals in CARD; c) the following categories in MATER: Materials Science, Biomaterials, Ceramics, Composites, Coatings, Characterization & Testing, Paper & Wood, Textiles.

The analysis of the data at the level of research teams shows that most of the groups use references and publications journals from different subject categories. In relation to publication journals, PHARM teams showed the highest number of different categories/team, followed by CARD and MATER groups (an average of 4.46 vs. 3.98 and 3.47 respectively, see table 10). Since teams that provided a higher number of publication journals were more likely to show an interdisciplinary behavior, the number of different categories was normalized according to the number of journals cited by authors, as shown in table 10. It can be observed that the same results are obtained with the new measure.

In relation to reference journals, CARD teams showed the highest number of different categories/team, followed by PHARM and MATER (4.27 vs. 3.87 vs. 3.43, respectively, see table 10). Within each area, the average number of categories/team was quite similar in publication and reference journals. The exception was PHARM teams, which showed higher variety of categories in publication than in reference journals (p<0.001).

Table 10. Journals of reference and publication. Interdisciplinary features.

	CARD (n=141)	**PHARM** (n=188)	**MATER** (n=237)	Significance
Reference journals				
% Journals of the area / team	0.32±0.29 Med=0.2 (0-1)	0.34±0.20 Med=0.2 (0-1)	0.31±0.32 Med=0.2 (0-1)	NS
No. Diff. Categories / team	4.27±1.30 Med=4 (1-8)	3.87±1.60 Med=4 (1-9)	3.43±1.44 Med=3 (1-7)	P<0.001
No. Categories /No. journals	0.86±0.29 Med=0.8 (0.2-2)	0.82±0.35 Med=0.8 (0.2-2)	0.70±0.32 Med=0.75 (0.2-2)	P<0.001
Publication journals				
% Journals of the area / team	0.29 ± 0.34 Med=0.2 (0-1)	0.35 ± 0.20 Med=0.2 (0-1)	0.31±0.29 Med=0.2 (0-1)	NS
No. Diff. Categories / team	3.98±1.59 Med=4 (1-7)	4.46±1.81 Med=4 (1-10)	3.47±1.31 Med=3 (1-8)	P<0.001
No. Categories / No. journals	0.90±0.32 Med=0.8 (0.2-1.75)	0.96±0.38 Med=1 (0.2-2.25)	0.74±0.27 Med=0.8 (0.2-1.6)	P<0.001

Notes: values expressed as average ± standard deviation, Med=median; Range= minimum-maximum.

4. Discussion and tentative conclusions

Our focus to study interdisciplinarity in this paper has been mainly empirical. Beyond the idea that interdisciplinarity is an emerging phenomena we have tried, first to define some dimensions associated to the idea of interdisciplinarity from different levels of analysis and then to apply them empirically for describing three different research areas. Additionally the exercise of exploring the different dimensions of interdisciplinarity provides some evidence on the nature of the structures that support the process of knowledge production.

Notable differences among the three areas analyzed emerge from this study. In fact, differences were expected, since the three areas were selected representing scientific disciplines with presumably different scientific habits. Pharmacology and Cardiovascular System are two biomedical disciplines, the first with a basic orientation and the second with a more clinical focus. Materials Science is a more recent and technology oriented discipline.

We believe that our empirical data give some new insights on three issues traditionally related in the literature with interdisciplinarity: the structures and organizational forms or research; research behaviors or practices, such us collaboration; and cognitive practices related to "boundary crossing" (borrowing and transferring knowledge) studied through publications.

4.1. Interdisciplinarity as a structural problem measured through educational training: Disciplinary diversity of areas and research teams.

The study of the disciplines or academic degrees obtained by researchers was analyzed as a way of studying interdisciplinarity. However, although our data showed that this type of analysis provides an interesting view of the scientific careers of individuals, it shows specialization rather than interdisciplinarity. Most degrees were obtained in traditional and well-delimited disciplines, while very few scientists obtained more than one. In fact, interdisciplinary training is hardly reflected in the academic degrees of researchers. Perhaps, this is because interdisciplinarity is not acquired through academic courses, but through everyday work experience.

Concerning the structures and organizational forms in research we have developed two different forms of measuring interdisciplinarity: *aggregate interdisciplinarity* versus *interdisciplinary composition of research groups*. In the first case, we study the disciplinary profile of each research area obtained through the aggregated data of academic degrees of the persons interviewed. The second approach is based in the analysis of the disciplinary composition of research team as a unit of analysis.

Focusing on the first approach, the higher homogeneity in the disciplinary background of researchers corresponded to CARD. It appears as a quite well delimited area, whose researchers come mainly from Medicine. However, the second approach that analyzes the presence of diverse disciplines inside the groups enables us to identify a significant degree of variety inside CARD teams, that is, integration of researchers from different disciplines into the teams. On the contrary, MATER showed the lowest average number of different disciplines within the research teams. PHARM shows an intermediate level of disciplinary diversity, sharing some features with each of the two other areas.

These data can be explained in the frame of traditional arguments of sociology of science about the general process of knowledge development (Klein, 1996; Dogan, 1996). What we have taken is a static picture of the research areas in a moment of time. But from our data we can see that knowledge in the different areas develops both through “specialization or branching” and “hybridization”. Both processes apparently represent forms of reduction of the traditional disciplinary approaches.

CARD appears to be in a process of “specialization” that creates new domains, in an overall research area dominated by a single profession: Medicine. Of course the more “clinical” oriented research precludes other professions to intrude into the practices of CARD that are directly associated to health care of patients. On the other hand, the higher diversity of CARD teams can be explained in the context of the working environment at hospitals. In the case of PHARM and MATER, we see that the researchers active in the area have a higher diversity in terms of their disciplinary backgrounds.

The case of MATER is especially interesting, since it is a sample of a hybrid area, built up by a process of convergence of specialized researchers coming from different backgrounds to work in the same knowledge field. However, MATER does not show a high team internal diversity, as we could expect from a hybrid area. Active researchers in MATER come from different disciplines, but more than half the teams are single-disciplinary teams. It seems that different disciplinary populations of teams coexist inside the area (teams of physicists, chemists, and so on). We could say that MATER is an interdisciplinary area, but the disciplinary-based organization is prevailing after all. It has researchers from different disciplines, but they are organized following the traditional disciplinary structures.

4.2.Interdisicplinarity in the context of research collaboration

Research collaboration has been described as a factor enhancing interdisciplinarity (Qin *et al*, 1997). However what collaboration brings to research teams could be complementarities in terms of new disciplines, but also could be a strategic move in favor of disciplinary redundancies. Thus, collaboration practice by itself cannot be considered as reinforcing interdisciplinarity.

Our data shows an inverse relationship between the area involvement in external collaboration and the degree of interdisciplinarity in research groups. It was observed that although CARD, was the area with more interdisciplinary groups in terms of composition, it was at the same time the area with less intensity for external research collaboration. On the contrary, we found that MATER teams collaborated the most. It seems that single-disciplinary teams require external collaboration more frequently to gain access to information beyond their own discipline. Although collaboration did not always imply interdisciplinarity, it was present to some extent in the external collaborations developed by 70-80% of the teams.

4.3. Interdisciplinarity and bibliometric indicators

Finally, we looked into knowledge flows of interdisciplinarity using bibliometric techniques. Analyzing the publication and reference journals we have found high flows of knowledge between the different research areas. Several observations can be derived from the analysis of the publication and reference journal titles cited by respondents. Firstly, it is interesting to note the high consensus existing among researchers on the list of reference journals, since it shows a high concentration in a core of high prestige specialty journals, mainly SCI journals. Even the lists of publication journals include mainly SCI-covered journals. Researchers try to obtain the highest visibility for their research results by using international journals. National journals are used very little, mainly as a publication journal. The area that reported the highest use of national journals was CARD, most likely due to the important role of Spanish journals in the clinical context.

Apart from the prestige of the journals, it is also interesting to note the broad spectrum of subjects in which SCI classifies the publication and reference journals. In fact, an average of two thirds of the titles cited by researchers, as publication or reference journals, did not belong to their same SCI subject categories or their own discipline. Researchers' interests were spread over a wide range of areas.

Considering the total number of journals mentioned by all the respondents, CARD showed the lowest diversity of categories, with a high concentration of responses in four closely related SCI categories (Cardiovascular System, Hematology, Peripheral Vascular Diseases and Internal Medicine). In PHARM and MATER, a higher diversity of categories was observed.

A higher interdisciplinary behavior was found for CARD and PHARM research teams than for MATER, since an average of 4 different categories were identified for the biomedical areas and only 3 in the latter one. These figures are quite high, since only five journals/team were requested. It is important to bear in mind that assignation of journals in more than one category was allowed, since multi-assignation itself was considered as an interdisciplinarity measure. In addition, it should be noted that in many cases specialty journals were cited together with general ones, cardiovascular researchers frequently cited i.e. internal medicine journals such as “Lancet” or “Medicina Clínica”. In any case, MATER teams not only showed the lowest interdisciplinarity according to the discipline of their members -as shown above-, but also the lowest average number of different categories/team for publication and reference journals.

4.4. Final remarks

What is clear is that there are interdisciplinary cognitive needs that could be solved by following different strategies by research groups. The use of reference journals (or publishing in those journals) from different areas is just one example; the recognition of the generalized use of knowledge and techniques from other areas was reported as a general feature, more intense in the areas with more disciplinary research groups, is another example. Another strategy could be the criteria used for incorporation of new members to research groups, either to maintain coherence or to diversify its research composition.

Finally we have to say that with this type of data we cannot make generative arguments, but we have the opinion that interdisciplinarity emerges in research areas as a double edge process: either as a process of jumping into a new area with people of different disciplines, in coherence with the traditional disciplinary research teams, or as a process of specialization in an big area traditionally dominated by a single group of disciplinary backgrounds, in which researchers from different areas join the research teams. Thus specialization-fragmentation-hybridization come all-together.

In summary, in all the three areas an important flow of knowledge among disciplines was detected. Research interests, as reflected in publication and reference journals, go far beyond their own disciplines. The different indicators used in this paper appear to complement one each other.

Acknowledgements

Funding for this research was provided by the CICYT through the III National R&D Plan (SEC97-1375). We thank our project colleagues for their collaboration in the design of the questionnaire, especially to Santos Barrigón, M. Teresa Fernández, Isabel Gómez and Elías Sanz. We also thank all scientists who participated in our survey. Maria Antonia Ruiz-Jiménez took care of the fieldwork and Visitación López, Javier Sánchez and Begoña Ferrari helped in the codification process. We are also grateful to two anonymous referees for their valuable suggestions. Special thanks to Cecilia Cabello who criticized the final version of the paper and helped us to improve its English.

References

Bordons, M.; Zulueta, M.A.; Romero, F.; Barrigón, S. (1999), Measuring interdisciplinary collaboration within a university: the effects of the Multidisciplinary Research Programme. *Scientometrics*, 46(3), pages 383-398.

Bourke, P.; Butler, L (1998), Institutions and the map of science: matching University departments and fields of research. *Research Policy*, 26, pages 711-718.

Caracostas, P.; Muldur, U. (1998), *Society, The endless frontier*. (European Community, Luxembourg).

Crane, D. (1972), *Invisible Colleges. Diffusion of Knowledge in Scientific Communities*. (The University of Chicago Press, Chicago).

Davis, M. (1992), Disciplines, interdisciplinarity and migration in family research. *Research Evaluation*, 2 (3), pages 177-187.

Dogan, M. (1996), The hybridization of social science knowledge. *Library Trends*, 45(2), pages 296-314.

Dogan, M.; Pahre, R. (1990), *Creative marginality: innovation at the intersections of social sciences.* (Westview Press, Boulder (Co), USA).

Elzinga, A.; Jamison, A. (1995), Changing Policy Agendas, in Jasanoff, S.; Markle, G.E.; Petersen, J.C.; Pinch, T. (Eds.), *Science and Technology. Handbook of Science and Technology Studies*. (Sage, London), pages 572-597.

European Commission (1995), *Green paper on Innovation*. (EC, Luxembourg).

European Commission (1998), *The Fifth Framework Programme 1998-2002*. (EC, Luxembourg).

European Commission (2000), *Towards a European research area*. (EC, Luxembourg).

Gieryn, T.F. (1983), Boundary work and the demarcation of science from non-science: Strains and interest in professional ideologies of scientist. *American Sociological Review,* 48, pages 781-795.

Gieryn, T.F. (1995), Boundaries of Science, in Jasanoff, S.; Markle, G.E.; Petersen, J.C.; Pinch, T.; (Eds.), *Handbook of Science and Technology Studies,* (Sage, London), pages 393-443.

Gibbons, M.; Limoges, C.; Nowotny, H.; Schwartzman, S.; Scott, P.; Trow, M. (1994), *The new production of knowledge*. (Sage, London).

Hagstrom, W.O. (1965), *The scientific community*. (Basic Books, New York).

Hinze, S. (1999), Collaboration and cross-disciplinarity in autoimmune diseases. *Scientometrics*, 46 (3), pages 457-471.

Institute for Scientific Information (ISI),http://www.isinet.com

Katz, J.S.; Hicks, D. (1995), The classification of interdisciplinary journals: a new approach. In Proceedings of the Fifth Biennial Conference of the International Society for Scientometrics and Infometrics, pages 245-254.

Klein, J.T. (1996), Interdisciplinary Needs: The Current Context. *Library Trends*, 45 (2), pages 134-154.

Morillo, F.; Bordons, M.; Gómez, I. (2001),An approach to interdisciplinarity through bibliometric indicators. *Scientometrics* (to be published)

Mulkay, M. (1975), Three models of scientific development. Mulkay, M. (1991), *Sociology of Science. A Sociological Pilgrimage,* (Indiana University Press, Bloomington), pages 51-61.

Nissani, M (1997), Ten cheers for interdisciplinarity: The Case for Interdisciplinary Knowledge and Research, *The Social Science Journal*, 34 (2), pages 201-216.

Palmer, C. L. (1999), Structures and Strategies of Interdisciplinary Science. *Journal of the American Society for Information Science,* 50 (3), pages 242-253.

Pierce, S. J. (1999), Boundary Crossing in Research Literatures as a Means of Interdisciplinarity Information transfer. *Journal of the American Society for Information Science*,.50 (3), pages 271-279.

Porter, A.L.; Chubin, D.E. (1985), An indicator of cross-disciplinary research. *Scientometrics*, 8 (3-4): pages 161-176.

Qin, J.; Lancaster, F.W.; Allen, B. (1997),Types and Levels of Collaboration in Interdisciplinary Research in the Sciences. *Journal of the American Society for Information Science*, 48 (10), pages 893-916.

Rip, A. (1994), The Republic of Science in the 1990s. *Higher Education,* 28 (1), pages 3-23.

Rivas, A. L., Deshler, D.; Colle, R.D.; González, R.N.; Quimby, F.W. (1996), Indicators of disciplinary differentiation: interdisciplinary linkages and adoption rate of biological innovations. *Scientometrics* 37(1), pages 63-86.

Sanz-Menéndez, L.; Borrás, S. (2001), Explaining changes and continuity in EU technology policy: The politics of ideas, in Dresner, S. and Nilbert, N. (Eds.), *The Dynamics of European Science and Technology Policies*, (Ashgate Press, Aldershot).

Small, H. (1999), A passage through science: crossing disciplinary boundaries. *Library Trends*, 48 (1), pages 72-108.

Storer, N.W.; Parsons, T. (1968), The discipline as a differentiating force, in Montgomery, E.B. (Ed.),*The foundations of access to knowledge,* (Syracuse University, Syracuse, New York), pages 101-121.

Tijssen, R.J.W. (1992), A quantitative assessment of interdisciplinary structures in science and technology: co-classification analysis of energy research. *Research Policy*, 21, pages 27-44.

Tomov, D.T.; Mutafov, H.G. (1996), Comparative indicators of interdisciplinarity in modern science. *Scientometrics,* 37(2), pages 267-278.

White, H.D.; McCain, K.W. (1989), Bibliometrics. *Annual Review of Information Science and Technology,*24, pages 192-203.

Younglove-Webb, J.; Gray, B.; Abdalla, Ch.W.; Purvis Thurow, A. (1999), The Dynamics of Multidisciplinary Research Teams in America. *The Review of Higher Education*, 22, 4, pages 425-440.

Zulueta, M.A.; Bordons, M. (1999), A global approach to the study of teams in multidisciplinary research areas through bibliometric indicators, *Research Evaluation* 8(2), pages 111-118.

Notes

[1] See, for example, Nissani (1997). In our survey 80% of the scientists interviewed mentioned interdisciplinarity as "necessary for knowledge creation and advancement".
[2] Analysis of data was carried out with the SPSS statistical package. Differences between means were analyzed with the Kruswal-Wallis test for non-parametric distributions.
[3] Scientists were required to include the "most important academic degrees, up to three", mentioning the highest academic degree obtained, the discipline and specialization.
[4] We consider options 3 and 4 as multidisciplinary groups.