Are There Research Teams in a "Little Science" Discipline such as Mathematics?[1]

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Abstract
The objective of this paper is to analyse the role of collaboration in Mathematics, which has been described as one of the less collaborative disciplines within the hard sciences. Scientific production of Spain in the area of Mathematics, years 1996-2001, was downloaded from SCI database, to which MathSci thematic codes were added. Trends in the collaboration between authors and centres in the area are analysed at the discipline level and differences between thematic specialities in behaviour and visibility are shown. A steady increase in the different collaboration indicators is observed in the area, although below that described for all areas combined. At the micro level research teams are identified through co-authorship analysis and an in-depth study of the most productive teams is developed. Individual and collective research coexists in the area. An exploratory study of the relationship between variables through multivariate analysis shows that the number of publications tends to increase with team size, while productivity tends to decrease; large teams are more likely to collaborate both at the national and at the international level; and national collaboration fosters interdisciplinarity. Expected impact is enhanced by international collaboration. Some conclusions with science policy implications might be drawn.

Introduction

Different reasons have been put forward to explain the increasing role of collaboration in research. Since research is becoming increasingly complex, collaboration between specialists in different disciplines is necessary to solve scientific inquiries and understand nature. Moreover, collaboration is a source of interdisciplinarity, which has emerged as a decisive factor in the production of new knowledge and has lead to the greatest scientific advances as a result of the cross-fertilization process that occurs among disciplines. Numerous studies on collaboration from different points of view have been published in the last years (see for example Newman, 2004; Melin, 2000; Katz, 1997).

The trend to collaborate varies according to the disciplines. It is the norm in "big science", in which large teams work in the development of sophisticated research projects (i.e. particle physics), while it is less frequent in certain "little science" areas such as Mathematics and especially in different disciplines of Social Sciences and Humanities. The fact that research in the latter needs neither large teams nor sophisticated laboratory techniques is the underlying reason for its low collaboration. However, collaboration tends to increase also in these traditionally low-collaborative areas, which are also learning to take advantage of the benefits of the interactions among scientists.

The objective of this paper is to analyse the role of collaboration in Mathematics, which has been described as one of the less collaborative disciplines within the hard sciences (Newman 2004). The following questions are addressed:

- Is collaboration increasing also in this area during the last years?
- Are we able to distinguish occasional collaboration from the more sustained collaboration that occurs within a research team? Are there research teams in the area?
- Are there differences in the trend towards collaboration of the different disciplines within the Mathematics area?

[1] This work was financed by the Spanish *Plan Nacional de I+D+I* (BFF2001-4415-E). We would like to thank Manuel de Leon and David Martin for their valuable contribution as experts in the field of Mathematics.

Proceedings of ISSI 2005, pages 305–309.
Edited by P. Ingwersen and B. Larsen.

- Is there any sign of positive effects of collaboration upon scientific research? Does it increase productivity? Does it increase impact of research? Does it foster interdisciplinarity?

Methodology
Scientific production of Spain in the area of Mathematics, years 1996-2001, was downloaded from the Science Citation Index (SCI) (CD-ROM edition). For the field delimitation the ISI classification of journals into categories was used and the following subfields were considered: Mathematics, Applied Mathematics, Mathematics-miscellaneous, Operations Research-Management Science, Statistics & Probability, Mathematical Physics, Social Sciences-Mathematical Methods. All types of documents were included in the study.

Bibliographic data obtained from SCI were standardised. Institutions were codified following the codification scheme developed at our centre. Author names were also normalised since the same scientist can be registered through several different names in SCI.

To enable the study of research topics thematic codes describing the content of each document were obtained from the specialised database MathSci, produced by the American Mathematical Society. It uses the "Mathematics Subject Classification" (MSC) to index documents. This classification includes more than 5000 terms sorted in a hierarchical structure with five levels of aggregation. For our analysis we have worked at the two-digit level, in which 59 different codes are distinguished. Documents published by Spanish authors in MathSci were retrieved and matched with documents downloaded from the SCI. MathSci thematic codes were added to SCI records.

For the study of collaboration different levels of analysis were established:

1. Collaboration between centres:
    - collaboration rate (percentage of documents with at least 2 centres)
    - national collaboration rate (% of documents with at least 2 domestic centres)
    - international collaboration rate (% of documents with at least 1 foreign centre)
    - average number of centres per document
2. Collaboration between authors

- average number of authors per document
- study of research teams

Research teams were obtained according to co-author analysis. The most productive author within a group is named "team leader", although he/she is not necessarily the intellectual leader of the group. All authors sharing at least 50% of their production with a leader were considered as pertaining to his/her group. The structure of teams was checked by experts in the area. An in-depth analysis was conducted for the most productive teams selected for fitting at least one of the following criteria: high production of the team leader, high production of the team or high team productivity.

Results
A total of 4940 documents were published by Spanish scientists in Mathematics journals during the period 1996-2001. Spain shows a certain specialisation in Mathematics, since it is responsible for 3.5% of the world production in the area, while its contribution to all the areas is around 2.5%. Moreover, the growth rate in the number of publications in the area has been higher that that corresponding to all topics. In fact, this is the area with the highest increasing trend in Spain during the last years.

The most productive subfield is Mathematics (41%), followed by Applied Mathematics (37%) and Mathematical Physics (23%). The categories of Applied Mathematics, Operations Res.-Manag. Sci. and Mathematical Methods-Social Sci. showed a growth rate above the average (table 1). In relation to the international visibility of the publications, the trend to publish in high impact factor journals (journals in the first quartile of the journal ranking in descending order of impact factor, by

disciplines) remained quite stable over the years. It was around 20% in most categories, being remarkable the high value in Mathematical Physics (60%).

Table 1. Publications of Spanish authors in Mathematics

Category	1996	2001	Total 1996-2001	% Doc. 1996-2001	Growth rate (%)	% Doc. Q1
Mathematics	263	401	2009	40.67	52	20.51
Applied Mathematics	199	416	1810	36.64	109	21.19
Mathematical Physics	155	234	1139	23.06	51	60.79
Statistics & Probability	54	89	444	8.99	65	25.00
Oper. Res.-Manag.Sci.	32	62	279	5.65	94	24.46
Mathematics, miscel.	25	25	184	3.72	0	20.33
Math.Meth.-Social Sci.	15	41	173	3.50	173	9.76
Total	597	1011	4940		69	

%Doc.Q1= % documents in journals located in the first quartile

Collaboration at the field level

An increasing trend in scientific collaboration was observed by means of different indicators: number of authors per document, number of centres per document and number of documents with more than one centre, although the values obtained are clearly below the average described for the whole country (table 2).

Table 2. Collaboration in Mathematical publications

Collaboration indicators	Mathematics		All Areas	
	1996	2001	1996	2001
Av.No.Authors/doc.	2.34	2.50	5.70	5.73
Av.No.Centres/doc.	1.78	1.94	2.30	2.56
% Doc. with more than 1 author	79%	81%	92%	94%
% Doc. with more than 1 centre	53%	58%	55%	63%
% Doc. with more than 1 national centre	22%	24%	33%	37%
% Doc. with at least 1 international centre	37%	40%	29%	36%
Total number of documents	597	1,011	18,454	21,086

The percentage of documents with more than one centre in Mathematics during 1996-2001 was quite similar to that of all areas (57% vs 60%), but a higher percentage of international collaborative documents (39% vs. 32%) and a lower percentage of national collaborative documents (24% vs. 35%) was observed. On the other hand, documents in collaboration in Mathematics increased quicker than those signed by just one centre (86% vs 50%), being the growth rate of national and international collaboration similar and quite above that corresponding to the whole country in all areas.

Spanish scientists in Mathematics collaborated mainly with scientists in the European Union, followed by North America and Latin American countries. The highest increase corresponded to collaboration with Latin American countries (170%), which in a lower rate was also described for all areas combined.

The highest collaboration was found in Mathematical Physics, which shows the highest percentage of documents in collaboration (68%) and especially, in international collaboration (47%) (table 3). It shows also the highest average number of authors and centres per document. Scientists in this subfield not only collaborate more frequently, but also with more partners. At the other end of the spectrum is Statistics and Probability: half of the documents are produced within a single centre, and it shows a low number of centres per document. It should be remarked that this discipline did not show the lowest number of authors per document, that is, the size of the teams does not seem to be smaller than in the other subfields.

Table 3. Collaboration by ISI categories

Category	Total No.Doc	% Internat. Collab. Doc.	% National Collab. Doc.	% Doc. without collab.	Av.No. Au/Doc.	Av.No. Centre/Doc.
Mathematics	2009	38.23	18.72	*46.84*	2.13	1.69
Statistics & Probability	444	31.53	22.07	*50.90*	2.61	1.86
Math.Meth.-Social Sci.	173	29.48	31.79	*46.24*	2.34	1.98
Mathematical Physics	1139	*47.15*	32.75	32.13	2.82	2.18
Oper. Res.-Manag.Sci.	279	30.82	22.58	*49.82*	2.40	1.70
Applied Mathematics	1810	34.42	22.98	*46.96*	2.36	1.75
Mathematics, miscel.	184	*40.22*	32.61	35.87	2.36	1.95

Research teams

Data shown above suggest the presence of collaborative research in Mathematics but we do not know whether it refers to occasional collaboration between scientists or to the maintained collaboration that takes place within a team. To distinguish both situations scientists were grouped according to frequency of co-authorship. Authors who signed at least 50% of their publications with a team leader were assigned to the corresponding team. Those who were not team leaders and signed occasionally with different authors were not assigned to any team.

For the identification of teams occasional authors with just 1 document in the period were removed. Co-authorship analysis among the remaining 2216 authors with more than 1 document in the period yielded 206 teams of 3 or more members, which included half of the authors and were responsible for 54% of the total production of the area. Half the authors were not included in any group because they worked alone or they maintained occasional collaborations with different scientists. Most of them were low-productive authors (half of non-assigned authors had only 2 documents in the period).

The fact that grouping of authors was possible indicates that research teams also play a role in Mathematics. However, different findings suggest that the role of teams in the area is not as relevant as in other disciplines. As compared to other areas previously analysed (Pharmacology and Cardiology, see table 4), teams in Mathematics include less percentage of authors than in other areas and they are responsible for less percentage of documents. Moreover, a few very productive authors were identified in Mathematics among the non-group authors, while only low-productive scientists were found in the other life science disciplines. In summary, individual and collective research coexist in the area.

Table 4. Grouping of authors in teams by co-authorship analysis

	Pharmacology	Cardiology	Mathematics
Doc. from teams	61%	75%	53%
Occasional authors	68%	68%	60%
Authors in teams	62%	79%	49%
Size of top teams (no.authors/team)	8	11	6

The size of the teams ranged from 3-14 scientists (average of 6 scientists per team). The scientific production of teams ranged from 11-49 documents/team. Half the teams published 3-4 documents per author in the period. Among the remaining teams 30% were less productive and 20% showed higher productivity. Differences in the behaviour of teams according to their thematic specialisation are being analysed.

The activity of a selection of 44 high productive teams is being studied in detail. The relationship between collaboration indicators and other variables related to the activity of the teams and several structural features is being studied through statistical multivariate techniques. Some preliminary results obtained through factor analysis were the following:

- the number of publications tends to increase with team size, while productivity tends to decrease (also described in other fields);
- the percentage of documents in national and international collaboration tends to increase with team size, that is, large teams are more likely to collaborate;
- national collaboration appeared to foster interdisciplinarity, since a positive correlation was found between percentage of documents in national collaboration and percentage of documents published in non-mathematical journals;
- international collaboration makes publication in high impact factor journals easier. Interestingly, this is accomplished with EU partners for some teams, and with Latin-American partners for others. Three different types of teams were identified according to their collaboration activity: a) groups with low collaboration, b) highly-collaborative groups which collaborate mainly with USA; and c) highly-collaborative groups which collaborate mainly with EU countries.

This study tries to contribute to the understanding of the role of collaboration in Mathematics. Some conclusions with science policy implications might be drawn. The fact that some regional research policies in Spain encourage scientists to join teams and work cooperatively through different instruments such as specific economic aids oriented towards "consolidated teams" may partly explain the increasing role of collaborative research in Mathematics.

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