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Scientific collaboration in Brazilian researches: a comparative study in the information science, mathematics and dentistry fields

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Abstract This study attempts to describe, in a comparative way, scientific collaboration and co-authoring activities and understanding of Brazilian researchers of productivity level 1 at the National Counsel of Technological and Scientific Development (CNPq). In order to do so, a questionnaire was sent to the researchers of productivity level 1 at CNPq in the Mathematics, Dentistry and Information Science fields, with questions about scientific collaboration and co-authoring activities. We analyzed the scientific production of the researchers who answered the questionnaire and we have identified that 78% of the participants consider that scientific collaboration and co-authorship are different activities, and the potential and usual number of research collaborators is between 2 and 3 in Mathematics and Information Science, and between 5 and 6 collaborators in Dentistry. Differences among fields were pointed out by identifying main collaborators and co-authors. The reasons for collaborating vary according to the nature of the research, however, the percentages are high in these three areas: "training of researchers and students", "desire to increase their own experience through the experience of others" and "increased productivity." From the analysis of the scientific production declared in their Lattes Curriculum, we have found that the average number of authors per publication in the field of Information Science is 2.2 authors, in Mathematics is 2.8 authors per publication, and in Dentistry the average is 5.3 authors per publication. We have concluded that scientific collaboration and co-authorship are terms assigned to different activities for the analyzed fields.

Keywords Scientific collaboration · Research collaboration · Co-authorship · Collaboration in science · Self-organization in science

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Introduction

Since the professionalization of research activity, collaborative work has become decisive for the development of research, forming a key element for obtaining results faster and in more complex and varied scientific fields. A new role has emerged for such collaborative research in modeling knowledge production development. In a broad sense, scientific collaboration has been defined as an activity developed by two or more researchers working in partnership on a joint project, with goals, obligations, commitments, coordinated investigations, and the sharing of intellectual, economic, and infrastructural resources. Thus, it is a social activity of interaction among individuals involved in research.

Scientific collaboration and co-authorship are considered distinct activities. The first one involves sharing intellectual resources, commentaries, and observations for work improvement, literature indications, and others contributions that influence the elaboration and development of the research. Co-authorship is the close co-operation result between or among partners, who collaborate intensively during the research development and take responsibility for the work content by means of joint signature, so that, in any situation, they can present and defend the original idea of work.

Research dealing with the theme of scientific collaboration has shown that papers produced by two or more authors tend to be more visible in the academic environment (Glänzel 2003; Persson et al. 2004; Royal Society 2011; Panet al. 2012), once they add up their tacit and scientific knowledge besides providing information sharing among authors and enabling deeper approaches, leading to more favorable conditions for production and improvement in the scientific field (Katz and Martin 1997; Balancieri et al. 2005; Olmeda Gómez et al. 2008).

Scientific collaboration can be considered a social communication network, comprised of researchers who act in groups to produce knowledge, which present some internal dynamics, developed as a self-organized system whose collective work can result in joint publications. Wagner and Leydesdorff (2005) adopted this perspective while analyzing international collaboration. Melin (2000) also adopted this perspective when investigating the reasons for and effects of collaboration for the individual scientist through a survey and a number of interviews. Especially in relation to the Brazilian science context, Mena-Chalco et al. (2014) present and analyze scientific collaboration networks in order to highlight particularities in the Brazilian researchers' collaborative dynamics from different fields.

The autonomous and self-ruling organization of contemporary science is a distinctive feature in relation to other organization systems, since much of the adherence of the researchers to scientific teams is voluntary and they have substantial autonomy to create, maintain, restructure, and dissolve their teams (Wang and Hicks 2014). In this context, the formation of research groups derives from common interests, motivated by social elements, internal and external to the scientific environment. These tend to vary according to the scientific context, from the micro level to the macro level, that is, from research groups, institutions, geographic regions, and even countries (Boschma 2005; Royal Society 2011; Pan et al. 2012).

The internal elements are mainly represented by the needs of the nature of each research, the specific knowledge, the researchers' ways of working, the development of the scientific field, and the desire/need to increase productivity and professional recognition. External elements include the evaluations of research promotion agencies, scientific

policies that rule the social environment in which researchers work, geographical proximity, a politics, and the economy.

According to Boschma (2005), there are five dimensions for proximity between individuals, and they can take place depending on the interaction level, such as scientific collaboration. In science, the proximity between authors can be motived by: *Geographical proximity*, which takes place when the distance (in this case, the proximity) between the actors is the factor that drives the interaction; *Cognitive proximity*, which consists of cases in which the individuals have close knowledge, such as research specialties, academic formation, and the same work field; *Organizational proximity*, which takes place when there is a coordinated group that works on certain research problems; *Social proximity*, which takes place among researchers of the same social context and is characterized by micro level relationships based on experiences or friendship relations, affinity and trust, which facilitates the tacit knowledge exchange and encourages a social and open attitude of "communicative rationality."

Institutional proximity is associated with the institutional framework at the macro level. An institution is defined as a set of "common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals and groups." Formal institutions (such as laws and rules) and informal institutions (like cultural norms and habits) influence the extent and the way actors or organizations coordinate their actions. Institutional, organizational and social proximities are distinguished by the aggregation level: The institutional environment at the macro level is associated with the institutional proximity notion and institutional arrangements at the micro level are related to organizational and social proximities. The social, organizational and institutional proximity dimensions can be strongly related.

Even though the geographical proximity is not a sufficient condition for scientific collaboration, it is an important motive for the choice of research partners. Studies on scientific collaboration have often shown that most scientific publications are produced by authors from the same country (Boschma 2005; Ponds et al. 2009; Royal Society 2011; Pan et al. 2012; Mena-Chalco et al. 2014; Sidone et al. 2016).

From the notion of Pierre Bourdieu's (1976) "scientific field," all fields are comprised of their own laws and behavioral patterns, called *habitus*. In this context, the structure of objective relations among the "agents" determines their actions within the field. When beginning his study of social capital, from action theory, Bourdieu (1976) developed the theory of practical sense, in which a person does not make thought-up choices, but acts according to the needs of practical life that demand immediate actions, and according to his/her *habitus.* Bourdieu (1994) defined a professional's *habitus* as an accumulation of techniques, references and a set of beliefs, tending to care about both the notes and the text. He argued that it is a practical sense of what must be done in each situation.

The *habitus* can be understood as action structures that are assimilated both in relation to social structure and to the personal responses of people to situations that occur throughout their lives. Thus, the habits of a scientific field are considered to be established from various criteria related to the field itself and to the social[1] environment external to it, which, even without interfering in its structure, tends to constantly affect it and be affected by it.

[1] We see the social environment as the whole context involving the scientific environment. For instance: Brazil is a social environment of this research, which aims at analyzing three fields of the Brazilian science. Therefore, the context involving the fields—Social and Scientific Policies, Economy and location are the same.

Considering the cumulative, localized, and tacit knowledge nature, the cognitive and epistemological differences, and the differences between the internal and external scope of each knowledge field, researchers in different fields behave and perform collaborative scientific activities in varied and different ways (Boschma 2005). This is observed by Glänzel (2003) in collaborative behavior in the Mathematics, Chemistry, and Biomedical Sciences fields, and by Mena-Chalco et al. (2014) in types of authorship and other scientific collaboration characteristics in all Brazilians knowledge fields.

We understand this variation is one of the main concerns of the researchers who use the co-authorship analysis as a methodology to evaluate the scientific collaboration in certain groups. Bearing this in mind, this study proposes to contribute to the visualization of Brazilian researchers' understanding of the Information Science, Mathematics, and Dentistry fields regarding scientific collaboration, as well as the behavior of these groups in their collaborative research activities.

We seek to answer the following questions: How do Brazilian researchers behave in the process of scientific collaboration? Is there equivalence in the understanding of the concepts and practices of scientific collaboration between Brazilian researchers in the fields studied? Is there a distinction between the terms scientific collaboration and co-authorship in the Mathematics, Dentistry and Information Science fields? Are there traits that determine how a contribution can be characterized as collaboration, and as co-authorship?

Based on the foregoing, this research aims to identify the understanding of the Brazilian researchers with a level 1 Research Productivity Grant (PQ1) from the National Counsel of Technological and Scientific Development (CNPq) in the Mathematics, Dentistry, and Information Science fields in relation to the notion of scientific collaboration and co-authorship, demonstrating the similarities and dissimilarities of understanding among the three fields. We analyze the understanding of these three groups on these matters: equivalence between the concepts of scientific collaboration and co-authorship; their experiences in collaborative research; the co-authors (s) resulting from their research; their perceptions regarding the number of collaborators that potentializes production in the scientific field; the usual number of collaborators in their research activities; the usual number of coauthors in the research published by them; their main collaborators; their main co-authors; and the reasons which lead them to conduct research in scientific collaboration. The paper also analyzes the scientific output published by the research participants in the period 2010–2012, corresponding to the last evaluation period of the CNPq candidates for the research productivity grant, in force in 2014, in order to verify the cohesion between the understanding, the perception, and the scientific practice of the researchers in each field.

In this research, we seek to contribute to the strengthening of the understanding and visualization of collaborative behavior, especially in Brazilian science, since this behavior results in cooperation for the development of research activities, whose results generate academic credits as well as broaden the possibility of scientific visibility and offer subsidies for reflection regarding the proposals of Brazilian Scientific Policies. It is also worth noting that Brazilian scientific production achieved significant growth in main international databases, especially in the last decade (2000–2010), highlighting the importance of understanding the Brazilian scientists' collaboration standards to identify the reasons that drive them to collaborative work and the benefits resulting from their collaborative scientific research (Glänzel et al. 2006; Royal Society 2011; Mena-Chalco et al. 2014).

We focus especially on the fields of Dentistry, Mathematics and Information Science because they belong to different knowledge areas: Biological Sciences, Exact Sciences, and Humanities, respectively. In addition, the fields present important indicators and

studies carried out in mainstream science, which allow possible comparisons and contextualization of Brazilian science with international scientific behavior, among them Melin (2000), Glänzel (2003), Boschma (2005), Leydesdorff et al. (2013), Mena-Chalco et al. (2014), and Sidone et al. (2016).

In Brazil, the National Council for Scientific and Technological Development (CNPq) gives productivity grants to researchers that have outstanding productivity levels in their fields (Rodrigues et al. 2017). According CNPq, the PQ1 research grant category congregates highly prestigious professors that have significant research output and consolidated action in training new PhDs in their scientific fields. Therefore, these researchers comprise a highly significant segment of Brazilian scientific thinking. The importance of this group also can be observed in studies by Picinin et al. (2016) and Rodrigues et al. (2017). Therefore, the central aim of this research is to highlight the collaborative behavior of researchers in the analyzed fields and their similarities and dissimilarities, both in the context of Brazilian science, and in relation to the forms of clustering identified in international science research.

Method

Initially, on August 1, 2014, by means of consulting the CNPq website, we identified the researchers of Research Productivity level 1 (PQ1) of the fields analyzed, resulting in: 140 Mathematics grants, 97 Dentistry grants, and 21 Information Science grants in force in that year.

After searching for the e-mail addresses of the researchers, we built an electronic questionnaire using Survey Monkey software, with questions regarding the researchers' understanding of the notion of scientific collaboration and co-authorship, their presence in their research, and their usual behavior in relation to these activities, namely: equivalence between terms; participation in research group activities; incidence of joint signature in their collaborative research; opinions about the number of authors that potentiates scientific production; usual number of collaborators; common number of co-authors in their works; who the main contributors are; and the reasons that drive collaboration in their scientific fields. We also requested that the researchers express their interest in participating in the study and acknowledge the objectives and procedures of the research, as well as their voluntary participation, so that the study meets the requirements of the Research Ethics Committee of the institution to which the research project is linked.

From the total number of identified researchers, due to the absence of addresses and shipping failures, there was success in sending the questionnaire to 99 addresses in the field of Mathematics, 88 in Dentistry, and 20 in Information Science. Of the 99 valid addresses found for the PQ1 fellows in the Mathematics field, only 23 of them answered the questionnaire, corresponding to 23.2% of the Mathematics researchers who received the questionnaire. Within Dentistry, of the 88 valid addresses, 21 researchers answered the questionnaire, resulting in 24.4% of the total PQ1 fellows of Dentistry. For the Information Science field, 10 researchers answered from a total of 20 PQ1 fellows (50%) with an identified electronic address.

The data were synthesized and presented in comparative tables, in order to facilitate the visualization of the similarities and dissimilarities of understanding and behavior among the fields. The Chi square test was used, with a significance level of 0.05, to verify the statistical significance of the observed differences among Dentistry, Mathematics, and

Table 1 PQ1 researchers' opinion on the author number that potentiates scientific production, by field

Number of authors	IS	%	Dentistry	%	Math	%	Total	%
Single author	–	–	–	–	–	–	–	–
2–3 authors	09	90	01	05	22	96	32	59
4–5 authors	01	10	14	66	01	04	16	29
6 or more authors	–	–	06	29	–	–	6	11
Total	10	100	21	100	24	100	55	100

Chi-square test: $p < 0.001$

Information Science fields regarding the analyzed variables. In order to calculate the Chi square for some of the tables, the categories have been grouped. Regarding Table 1, the categories have been grouped as: "2 or 3 authors" and "4 or more authors". For Table 2, the categories have been grouped as: "1 or 2 collaborators" and "3 or more collaborators". The individual author category has not been considered at the test for Tables 1 and 2. For Table 3, the categories have been grouped as: Individual research, 1–2 collaborators, 3–4 collaborators, 5–6 collaborators and 7 or more collaborators. Considering that in Tables 4, 5 and 6, the categories are not independent, the Chi square test was used for each category. As for "graduate students" and "professors of foreign institutions" the fields of Information Science and Dentistry have been grouped for the Chi square test.

In order to better understand the practice of co-authorship among participating PQ1 fellows, we verified the Lattes[2] Curriculum of each respondent of the questionnaire, identifying details about the researchers' academic training and publications of papers, books, book chapters, and complete papers in the annals events in the 2010–2012 period, which corresponds to the last evaluation period of CNPq candidates for research productivity grants in force in 2014. The data obtained from the questionnaire and the results of the respondents' publications were compared and analyzed with the support of the relevant scientific literature, highlighting the characteristics of the self-organized systems.

Analysis of results and discussions

Initially, PQ1 fellows from the Mathematics, Dentistry, and Information Science fields were asked about the equivalence of the terms "scientific collaboration" and "co-authorship" in order to guide the analysis of the subsequent responses. Of the total of 23 participants in Mathematics, 78% (18) believe they are different activities. In Dentistry, 71% (15) of the respondents share this same opinion. In the group of Information Science participants, all responded to consider the terms scientific collaboration and co-authoring as different activities.

The Chi square test showed that there is no statistically significant difference among the fields of Dentistry, Mathematics, and Information Science (IS) regarding the equivalence

[2] Lattes Curriculum is a virtual platform developed by CNPq which integrates a database of researcher curriculums, institutions, and Brazilian research groups in the same information system. We estimate that all researchers linked at public research institutions in Brazil own a Lattes Curriculum, where their main technical and scientific productions are recorded. The platform can be accessed at this address: <lattes.cnpq.br/>.

Table 2 PQ1 researchers' usual collaborator number, by field

Usual collaborator number	IS	%	Dentistry	%	Math	%	Total	%
Individual research	–	–	–	–	1	04	1	02
1 to 2 collaborators	3	30	5	24	17	74	25	46
3 to 4 collaborators	2	20	6	28	5	22	13	24
5 to 6 collaborators	3	30	8	38	–	–	11	20
7 or more collaborators	2	20	2	09	–	–	4	08
Total	10	100	21	100	23	100	54	100

Chi square test: $p < 0.005$

Table 3 PQ1 researchers' most common co-author number, by field

Most common author number	IS	%	Dentistry	%	Math	%	Total	%
Individual author	01	10	–	–	05	21	06	11
2–3 authors	08	80	03	14	15	65	26	48
4–5 authors	01	10	11	52	04	17	16	29
6 or more authors	–	–	07	34	–	–	07	12
Total	10	100	21	100	23	100	54	100

Table 4 PQ1 researchers' main collaborators, by field

Main collaborators[a]	IS	%[b]	Dentistry	%[b]	Math	%[b]
Undergraduate students	05	50	05	25	03	14
Graduate students[c]	10	100	16	80	08	36
Professors from the same department	06	60	13	65	10	45
Professors from other Brazilian departments/institutions	09	90	11	55	11	50
Professors from foreign institutions[d]	04	40	08	40	16	73

[a] Among the respondents, two researchers have ignored the question: one from Mathematics and one from Dentistry, since they responded that collaboration and co-authorship are synonymous

[b] Percentage calculated in relation to the total number of respondents in the field (10 researchers from IS, 20 from Dentistry, and 22 from Mathematics)

[c] $p < 0.001$

[d] $p < 0.025$

of the terms scientific collaboration and co-authorship. Thus, the differences observed in the sample cannot be inferred for the population of PQ fellows from these fields, based on the analyzed samples.

Considering that 78% of the participants in this research believe that the terms collaboration and co-authorship are not synonyms, we can say this understanding meets the observation of Katz and Martin (1997), pointing out that there are many situations in which collaborative activity does not result in co-authored papers and that, on the other hand,

Table 5 PQ1 researchers' main co-authors, by field

Main co-authors	IS[a]	%	Dentistry[a]	%	Math[a]	%
Undergraduate students	3	30	05	24	03	14
Graduate students[b]	9	90	16	76	09	39
Professors from the same department	6	60	13	62	09	39
Professors from other Brazilian departments/institutions	9	90	11	52	11	50
Professors from foreign institutions[c]	4	40	08	38	16	73

[a] Percentage calculated in relation to the total number of respondents in each field (10 researchers from IS, 21 from Dentistry, and 23 from Mathematics)

[b] $p < 0.001$

[c] $p < 0.025$

Table 6 Main reasons for PQ1 researchers to collaborate, by field

Reasons	IS	%[a]	Dentistry	%[a]	Math	%[a]
Desire to increase scientific popularity, visibility and personal recognition	2	20	6	28	4	17
Increased productivity	6	60	12	57	12	52
Rationalization of the scientific workforce use and time spent on research	3	30	9	43	4	17
Decrease of error possibility[b]	3	30	7	33	1	04
Achieving or expanding financing, resources, special equipment and materials[c]	4	40	11	52	2	09
Increase of science expertise	1	10	6	28	5	22
Possibility of "attacking" major research problems	4	40	9	43	12	52
Growing scientific professionalization	3	30	4	19	4	17
Desire to increase one's own experience through the experience of others	6	60	17	81	14	61
Desire to carry out multidisciplinary research[d]	5	50	15	71	6	26
Strength union to avoid competition	1	10	2	09	2	09
Training of researchers and students	9	90	14	67	12	52
Need for external opinions to confirm or evaluate a problem[e]	5	50	11	52	4	17
Possibility of greater research dissemination	4	40	7	33	7	30
A way to keep concentration and discipline in the research until results are handed to the rest of the team	1	10	1	05	2	09
Sharing the enthusiasm for a research with someone	5	50	7	33	16	69
Physical need of working close to others, for friendship and pleasure of being with someone you like	4	40	1	05	5	21

[a] Percentage calculated in relation to the total number of respondent researchers in the field

[b] $p < 0.05$

[c] $p < 0.01$

[d] $p < 0.025$

[e] $p < 0.05$

there are cases where cooperation is at the most peripheral and, nevertheless, results in co-authoring in the publication. These behaviors may be due to the difficulty in defining scientific collaboration, resulting in part from the fact that the notion of scientific collaboration is often interpreted as a social convention among scientists and little is said about the formal and informal relationships that define where this type of activity begins and ends in the scientific environment. Moreover, what is considered "collaboration" for some researchers, for others may be only a flexible grouping or an informal set of relationships and communications (Katz and Martin 1997).

When asked whether their collaborative activities resulted in co-authorship, 74% (17) of researchers in the Mathematics field answered that there was co-authoring in all or most of their collaborative activities and 14% (3) stated that their collaborative activities resulted in publication only in some cases. In this field, one researcher replied that his/her collaborative activities did not result in co-publication and another researcher replied that he/she does not act in cooperation. Analyzing the Lattes Curriculum of the researcher who declared that he/she had not had collaborative experiences, it was identified that although this researcher published an important part of his/her productions individually, he/she also co-authored a publication in the 2010–2012 period, specifically with graduate students. This result may mean that for this researcher co-participation in graduate-oriented work does not characterize collaboration, unless there is participation in the project, rather than in the student's project.

For the field of Dentistry, 76% of the researchers stated that their collaborative activities resulted in a joint signature in all or most publications and 23% stated that there was a joint signature in only a few cases. The assertion of having collaborative research experiences on the part of all respondents in this field and the high incidence of joint signature suggest that in Dentistry, an experimental field, there is a need for shared work to achieve a common goal, not just for the sharing of materials and equipment, resulting in a joint signature of the results obtained.

For 60% of the PQ1 fellows in Information Science, only some of their collaborative activities resulted in co-authorship. The other 40% of the respondents reported that there was joint signing in all or most of their activities. It should be emphasized that their experiences and practices regarding scientific collaboration are in agreement with the understanding of the meaning of the terms "Scientific Collaboration" and "Co-authorship", since all IS respondents stated that scientific collaboration and co-authorship are not synonymous, which indicates an understanding of the meanings of these terms.

Table 1 shows the position of the researchers in relation to the number of authors who are considered to potentiate the production in their scientific field, in which by the Chi square test ($p < 0.001$) we can observe a significant statistical difference among the fields. The researchers in the fields of Information Science and Mathematics tend to have a similar position while researchers from the Dentistry field tend to consider that bigger teams are necessary to potentiate scientific production.

In the Information Science and Mathematics fields, 90% of the fellows consider that 2–3 authors potentiate scientific production. In each of these fields, only one PQ1 researcher stated that groups with 4–5 authors optimize scientific production. Thus, in these two fields teamwork is preferred as the most productive work, rather than individual work, but they consider teams should be small. This result is close to Mena-Chalco et al.'s (2014) study for both fields.

This result also is in line with that obtained by Queiroz and Moura (2016), in which they analyze production in the Brazilian scientific field of Mathematics, based on Web of Science (2004–2013). The authors note that the average number of authors per paper is 2.6

and the standard deviation is 1.15. It is also worth noting that 70% of the Brazilian scientific papers analyzed were published with two (39.2%) and three authors (29.9%), and that the number of papers with a larger number of authors was significantly lower.

In the Dentistry field, in the opinion of 95% of the respondents, teams with at least 4 authors are needed in order to potentiate scientific production, the groups with 4–5 authors being the most indicated. We should note that no participant in the three fields considers simple authorship to enhance the production of knowledge, even the researcher in the Mathematics field who answered that he/she never participated in group research.

From the data collected in the Lattes Curriculum of the fellows, it was possible to identify that the average number of authors per publication in the IS field is 2.2, in Mathematics is 2.8 and in Dentistry is approximately 5.3 authors per publication, values close to those indicated by the researchers in relation to the number of authors that potentiates production in the scientific field (Table 1). Thus, we observe the cohesion between the researchers' understanding of the ideal number of participants in a research project to strengthen scientific production and their investigative practice, which suggests that almost all of these researchers are working within their ideal, as for research teams.

Table 2 presents the usual number of collaborators in the research of the respondents of the questionnaire, by scientific field, in which we observed a significant statistical difference among the fields (Chi square test: $p < 0.005$). The researchers from the IS and Dentistry fields tend to have a more similar position in comparison to the researchers from the Mathematics field: In general, IS and Dentistry researchers prefer working in bigger teams. On the other hand, most of the researchers from the Mathematics field tend to work in smaller groups of collaborators (up to two collaborators).

It is worth mentioning that the researchers were asked about the number of collaborators, without presenting a concept or indicating whether or not there is a distinction between terms. Thus, their responses were based on individuals' understanding of this activity.

We also observe that the usual number of collaborators varies considerably in the Information Science and Dentistry fields. In IS, all fellows point out that their research involves collaborators. Among them, 50% utilized collaboration of 1–4 researchers, siding with the results observed in Table 1, in which all the researchers in this field affirm that research signed by 2–5 authors potentiates scientific production. Thus, 50% of the respondents work in larger groups in this field, involving at least 5 researchers, which suggests that they work in several subgroups, as it will be validated by the results to be presented in Table 3.

Variation also happens among the researchers in the Dentistry field, since 38% of the respondents stated that the usual number of collaborators varies between 5 and 6 in their research, while 28% declared to have between 3 and 4 collaborators and 24% said they had only 1 or 2 collaborators. Two respondents said they had 7 or more collaborators in their research. Thus, the number of collaborators is consistent with the number of co-authors indicated as the number that potentiates scientific production by the respondents.

The number of collaborators observed in the fields of Information Science and Dentistry may indicate that the way researchers work may vary, even if they belong to the same field and the nature of the research is the same. Yet, this may also happen because of the methodological differences among the research, as they tend to increase or to restrict the number of collaborators according to the research. This may also be only an indication of the lack of an elaborated notion about the collaborator role in research.

In the Mathematics field, the number of collaborators reported was less dispersed among the respondents, which indicates similar views about the collaborator role in their research,

since the majority (74%) said they have usually 1 or 2 collaborators and a small percentage (22%) reported having a slightly larger group (between 3 and 4) of collaborators in their research. This fact may indicate a certain uniformity in the research field types (of a theoretical nature), with knowledge construction carried out in a more similar way, using a deductive and structured methodology to obtain the results.

Table 3 shows the most common number of co-authors in the researchers' works, in which we can observe a significant statistical difference among the fields. Researchers from the Information Science and Mathematics fields tend to publish in smaller co-authorship groups than researchers from the Dentistry field.

The majority (65%) of researchers in Mathematics usually publish papers signed by 2–3 authors. Thus, the most common number of coauthors in PQ1 respondents' surveys is similar to the usual number of collaborators indicated by them (Table 2), suggesting little variation between the collaborative practice and the practice of co-authorship in their research. It is also worth noting the cohesion of these results (Tables 2, 3) with that observed in Table 1, suggesting equivalence between the scientific practice and the perception of the ideal size of groups of co-authors to potentiate the production of science.

Yet, a low percentage of researchers in Mathematics said that they publish in groups of 4–5 coauthors, a tendency similar to that pointed to by the usual number of collaborators. It is also worth mentioning that five researchers cited individual authorship, although only one author responded that he/she does not work in groups, which suggests that not all collaboration has generated papers in co-authorship.

In Information Science, the majority (80%) of the respondents declared to publish in groups of 2 and 3 authors. Only one researcher claimed to publish in larger groups (4 or 5) and one in individual authorship. We see the values presented for the number of collaborators and co-authors are in harmony, since the number of collaborators is 1 and 2 and the number of co-authors is 2 and 3 (counting the researcher himself/herself). On the other hand, although all researchers have stated that they have collaborators, and thus they are not isolated researchers, there are PQ1 researchers for whom collaboration does not always result in co-authorship. We believe this result is in agreement with Katz and Martin (1997), according to whom co-authorship does not always reflect scientific collaboration because some researchers can unite their efforts, share knowledge, but publish their results separately.

Among the Dentistry researchers, the majority (54%) stated that they work with groups of 4–5 authors. A significant percentage (30%) indicated that they work in co-authoring with 6 or more authors. This result is close to Mena-Chalco et al.'s (2014) study, in which they evidenced that the largest coauthor number in Brazilian science occurs in the Biology field. We observe that the number of co-authors and collaborators are close in the Dentistry field, with the first among 4 and 5 co-authors, and the second among 5 and 6 collaborators.

The results found for the three fields are in agreement with Smith's (1958) observation, in which theoretical works generally produce publications with fewer co-authors than experimental works. We can see that the number of authors that potentiates production in the three scientific fields is the same identified for the usual number of coauthors in research, respectively, which indicates understanding about the subject and behaviors according to their perspectives.

We can also observe that the results obtained for the types of authorship identified as those that potentiate scientific production, the usual number of collaborators, and most common number of coauthors in the research of the participants reveal that the relations among the researchers and the actions that guarantee the identity of the collaboration system are conditioned to the structure of their organizations. This structure, represented

by the way of working in each field, shows the self-organized characteristics of the analyzed fields as the size of the groups formed vary considerably among Mathematics, Dentistry, and IS.

Table 4 shows the PQ1 researchers' main collaborators in which a wide range of number of collaborators is observed in the three fields, since all the categories showed higher or lower numbers. However, only the categories "Graduate students" and "Professors of foreign institutions" presented significant statistical difference among the fields. For the categories "Undergraduate students" and "Professors from other Brazilian departments/institutions", although the differences among percentages can be seen in at least two fields, these differences are not statistically significant. The category "Professors from the same department" presents close percentages among the three fields.

All researchers in the Information Science field highlighted graduate students among their main collaborators. This behavior agrees with the observation of Katz and Martin (1997), according to whom collaboration often occurs between teachers and students. Thus, we believe that for the researchers in this field, even though they may have broader and more consolidated knowledge, they consider a graduate student a collaborator. Therefore, this result points out that, in this field, the process of knowledge production is considered bilateral, between advisors and students, where the contribution of the student is of equal importance to generate knowledge.

We also identified that almost all the PQ1 researchers in Information Science consider that professors from other departments or institutions are also included as their main collaborators. The predominance of domestic collaboration in Information Science shows a difference in collaborative behavior in relation to the tendency of international behavior, whereas in most of the countries included in the Social Science Index the international co-authorships are more evident (Leydesdorff et al. 2013).

In the IS field the collaboration with researchers from foreign institutions is less frequent (40%). This suggests that Information Science's Brazilian scientists prefer domestic collaborative activity, and that their resulting papers are published in national or regional journals, mainly in the national language. This implies a lower-than-average visibility (Glänzel et al. 2006).

According to Leydesdorff et al. (2013), Social Sciences have generally shown distinct citation patterns in relation to Natural Sciences. In general, Social Sciences researchers claim that they are not as well funded by the national research funding organizations, getting a much smaller share of total funds. As a result, Social Sciences are more likely to be funded locally, and therefore the works tend to focus on more local or even idiosyncratic problems, which can explain the preference for endogenous publications.

In addition, Pan et al. (2012) identified the relationship between the national expenditure per researcher and the scientific output impact of a country. They showed that it is impossible for a country to be better than the world average of citations per paper if its average spending per researcher per year is low.

In the Dentistry field, graduate students are also the main collaborators of the respondent researchers, but with a lower number (76%), followed by professors from the same department (56%) and professors from other departments or institutions (52%). As for the Information Science field, professors from foreign institutions and undergraduate students are not the main collaborators of the PQ1 researchers. In this field, the results differ from those identified in the literature. It is worth noting that those responses obtained in IS and Dentistry agree with the national collaboration trend in which domestic collaboration is the most present. According to the Royal Society (2011), more than 70% of Brazilian scientific production is published only by native researchers.

Concerning to domestic collaborations, the distinction between inter-institutional and intra-institutional collaboration may be related to different research characteristics. According to Iglič (2017), inter-organizational collaboration is a vehicle for resource mobilization. Researchers search for colleagues from other institutions to get access to additional resources and to apply jointly for funds from national research funding agencies. On the other hand, intra-organizational collaboration seems to be related to labor division, especially in laboratories and highly competitive research environments.

According to Sidone et al. (2016) the geographic distance effect on collaboration relationships varies according to knowledge areas. A distance of 400 km between two researchers from Agricultural, Exact, or Earth Sciences reduces the probability of collaboration by 65% whereas in Arts and some Humanities (Linguistics and Letters) fields this distance reduces the probability of collaboration by 40%. In addition, authors state that total proximity (zero geographic distance) is associated with 100% collaboration probability.

Most Mathematics fellows stated that the main partners in their research are professors from foreign institutions. This is also observed in Mena-Chalco et al.'s (2014) study, where the international co-authorship practice is larger in the Exact Sciences than in the Social Sciences. In addition, Melin's (2000) study showed that prestigious fellowship researchers prefer to publish in co-authorship with researchers from foreign institutions. This result also agrees with Queiroz and Moura (2016), who observe the English language supremacy in Brazilian papers from the Mathematics field, corresponding to 99.5% of the published papers, mainly disseminated in British and North American journals and with foreign co-authors, mainly from the United States, France, Germany, Italy, China, Spain, England and Canada.

The results also resemble the ones presented by Frame and Carpenter (cited by Subramanyam 1983), who observe that basic and pure sciences, such as Mathematics, are the ones that perform the most international collaboration. In this field, graduate students are not the main collaborators with most of the PQ1 researchers.

When analyzing the Lattes Curriculum of the PQ1 researchers in the Mathematics field, we saw that seven of them are foreigners who work in Brazilian institutions, of which two are partially trained in Brazil. Moreover, it was identified that 11 of the 23 fellows from the Mathematics field had full or partial training abroad, making only five of the participants Brazilian with training in Brazil. This fact may justify the appointment of professors from foreign institutions as main collaborators, since active participation in foreign institutions tends to be one of the factors facilitating international collaboration. It was also observed in the scientific production of the Mathematics researchers that most of their co-authors are linked to American institutions, evidencing the USA's predominance as the origin country of the Brazilian researchers' main collaborators (Glänzel et al. 2006; Royal Society 2011; Leydesdorff et al. 2013).

Also noteworthy, the professors from other departments or institutions are among the main collaborators with most of the participating fellows of the three fields. Endogenous collaborations (professors from the same department, graduate students, and undergraduate students) appeared with low frequency among the answers of the PQ1 fellows of these fields.

Thus, PQ1 researchers from the Mathematics field in Brazil presented quite different behavior from fellows in Information Science and Dentistry, with collaborative activity marked by the internationalization of their partnerships, while the latter two fields reported similar tendencies for the selection of partners. It is highlighted that in relation to the participant researcher group from the Mathematics field, results of Sidone et al. (2016) are

ratified because these researchers prioritize international collaboration and co-authorship, instead of domestic relations, as evidenced in the recent publications of the main collaborators and co-authors. In the Mathematics field, we consider that cognitive proximity between authors stands out. According to Boschma (2005), this proximity occurs between individuals who share the same knowledge base and experience. In this case, collaboration tends to broaden the cognition reach.

Table 5 presents the main coauthors declared by the participants, in which there is little variation regarding which are considered their main coauthors and their main collaborators (Table 4), mainly for the Dentistry and Mathematics fields, although the majority has stated that the terms "scientific collaboration" and "co-authorship" are assigned to different activities. Significant statistical differences are observed in the same categories in Table 4: "Graduate students" and "Professors from foreign institutions".

Among researchers in the Mathematics field, most stated that their main coauthors are professors from foreign institutions, followed by faculty from other departments or institutions. Among the respondents in this field, two stated that researchers from the same department are collaborators, but not co-authors, and one of the researchers considers graduate students as collaborators and not co-authors, while others think the reverse, considering graduate students co-authors and non-collaborators.

Fellows from the Dentistry field say that their main co-authors are graduate students (76%), followed by professors from the same department (62%), and professors from other departments or institutions, in the same order of indication for collaborator. Researchers from foreign institutions and undergraduate students represent the minority among the co-authors of the respondents. We ought to notice that among the 21 respondents in this field, 13 consider that their main collaborators are also their main co-authors, especially those who answered that collaboration is synonymous with co-authorship. The other three emphasized that the collaborator is not always also a co-author, so only some individuals mentioned as collaborators were listed as co-authors. Still, three other researchers answered that the students/graduate students are only co-authors, not collaborators.

The Information Science field presented different results, though not very divergent, regarding its main co-authors. Among the main co-authors are graduate students and professors from other departments and institutions, each with 90%. It is noteworthy that only one of the researchers interviewed stated that graduate students are only collaborators and not co-authors. Professors from the same department come next. Professors from foreign institutions appear as main co-authors to less than half of the participants and undergraduate students as least often. Still, five respondents say that undergraduate students are their collaborators, however, only three of them stated that these students are also their coauthors, which indicates that in the research of these three fellows there is the participation of undergraduate students, but the researchers do not consider that the work they develop is set up as partnership/co-authorship.

Based on the work of Subramanyam (1983), some collaborative activities involve the performance of technical/practical activities such as laboratory experiments, data collection, and analysis, a fact that may explain why some individuals are more collaborators than co-authors. In addition, the main communication media of scientific publications are quite careful concerning work evaluation and generally require more solid and mature research results, such as major research project outcomes, as well as master's and doctoral research. The choice of main collaborators and co-authors by the fellows of the three analyzed fields further highlights the spontaneity of the interaction process of the scientists, since, although there is a general tendency for each field, there is still variation among the

partners chosen by the participants, indicating self-organization in the process of selecting their teams.

Table 6 presents the reasons for carrying out research in scientific collaboration, declared by the PQ1 fellows, by field. Among the main reasons indicated by the PQ1 researchers of the three fields, with high percentages, we highlight "The training of researchers and students", with 90% indication by the researchers from the IS field, 67% of Dentistry, and 52% of Mathematics. This shows that collaboration often occurs among professors and students, although some authors do not consider the professor/student relationship as collaboration (Katz and Martin 1997), as some of the researchers in Dentistry do.

Within the common motivations, we also highlight "The desire to increase our own experience through the experience of others", with a percentage above 60% in all three fields. This motivation can be characterized by what Bourdieu calls the search for scientific authority. This is defined as technical capacity and social power and also seen as the "monopoly" of scientific competence, understood as the capacity to speak and act legitimately (that is, with authority), which is socially bestowed upon a determined agent (Bourdieu 1976).

In a complex and self-organized collaboration system, scientific authority can be translated into the position the researcher occupies in the system, as well as in a network of scientific collaboration. The most central researchers exert influence upon others. Based on the Theory of Self-Organization (TSO) proposed by Debrun (1996), these elements have the function of directing a group of people in a non-hegemonic way, because of influence and not power.

We also see that among the main reasons for collaboration the three fields indicated "the increase of productivity", with percentages between 50 and 60%. The "Possibility of 'attacking' major research problems" is also presented as common motivation in the three fields, with 40% in IS, 43% in Dentistry, and 52% in Mathematics. These reasons are related to the competitiveness of the academic environment, which is subject to contemporary societal pressure, especially from science funding institutions, in order to generate more results, leading to the need to cooperate with other scientists as a form of uniting complementary knowledge. This feature of "Big Science" is due to the need to obtain help and resources to make research projects feasible, where multi-, inter- and trans-disciplinary teams were formed to work on applied or on real-life problems (Iglič 2017).

For the Information Science field, among the main reasons that drive scientific collaboration, we identify: the training of researchers and students (90%); followed by increased productivity, and the desire to increase one's own experience through the experience of others, both with 60% indication. Half of the researchers also indicated these reasons to collaborate: desire to carry out multidisciplinary research; need for external opinions to confirm or evaluate a problem; and sharing the enthusiasm for research with someone. We understand that these motives, indicated by most of the researchers in IS, are related to the improvement and enrichment of scientific knowledge and to the increase of science indicators.

Among the Dentistry researchers, the main reason stated for collaboration is the desire to increase their own experience through the experience of other scientists (81%), followed by the desire to carry out multidisciplinary research (71%), and the training of researchers and students (67%). With percentages between 50 and 60%, additional reasons include: increase of productivity; achieving and/or expanding financing, resources, special equipment and materials; and need for external opinions to confirm or evaluate a problem. We should note that the reasons indicated by the Dentistry researchers are mainly focused on

research improvement and the scientific development process, as well as obtaining material and economic resources for funding experimental research.

Researchers in the Mathematics field emphasized the sharing of enthusiasm for research (69%), followed by the desire to increase their own experience through the experience of other scientists (61%). Furthermore, for 52% of respondents, increased productivity, the possibility of "attacking" major research problems, and the training of researchers and students are significant reasons for conducting research in scientific collaboration.

The "Desire to increase scientific popularity, visibility and personal recognition" presented low and close percentages for the three fields: 20% of the researchers in IS, 28% in Dentistry and 17% in Mathematics. Among the least compelling reasons for the respondents in the three fields, we identified: "Strength union to avoid competition"; "Possibility of greater dissemination of research"; "A way to keep concentration and discipline in the research until the results are handed to the rest of the team"; and "Increase of science expertise."

Other motivations presented variable percentages in the fields, among them, "the rationalization of the use of the scientific workforce and the time spent on research", more significant in Dentistry (43%) than for researchers in Mathematics (17%). This dissimilarity may be due to characteristics of the nature of research in these fields. Since Dentistry is an experimental science, it generally lacks more human resources due to laboratory tests, tests on living beings, while the field of Mathematics develops mostly theoretical studies and does not depend on practical experimentation for proofs.

The "decrease of error possibility" appears as a significant and similar motivation for the researchers in the fields of Dentistry (33%) and Information Science (30%), however, it is almost nonexistent among Mathematics researchers, since only one (4%) researcher indicated this motivation. Likewise, the "need for external opinions to confirm or evaluate a problem" appears as motivation for half the researchers in IS and Dentistry, but in Mathematics only four (17%) researchers point out this motivation. We believe these differences can be derived from the empirical nature of the first two fields, where the evidence depends on experimental proof, and the theoretical nature of Mathematics.

The "desire to perform multidisciplinary research" also appears as a motivation with significant percentages for researchers in Dentistry (71%) and IS (50%), however it is a motivation for few researchers in Mathematics (26%). We consider that this characteristic can be derived from the fact that Information Science is comprised of a branch of the social sciences, which involves studies on social activities and human behavior. Katz and Martin (1997), influenced by Hagstrom,[3] argue that applied research, as well as experimental research, tend to be more interdisciplinary and research on a problem may therefore require a wide range of skills that a single individual, or even a single institution, probably does not have. In this context, the applied social sciences are made up of sciences that have absorbed characteristics of the human sciences and of the exact sciences, just like Information Science itself, which although it is an applied science, does not lack many material resources for the research development like equipment or tools.

We also emphasize that "Achieving and/or expanding financing, resources, special equipment and materials" are also close in Dentistry (52%) and Information Science (40%) and different in Mathematics (9%). We understand this behavior is due to the nature of the fields, since Mathematics does not require large investments of material and financial resources. Another reason that may be related to the nature of research is the "Desire to perform multidisciplinary research", since the fields of Information Science (50%) and

[3] Original reference: W.O. Hagstrom. *The Scientific Community*. Basic Books, New York, 1995.

Dentistry (71%) are closer, and there is a great difference in Mathematics (26%). This result is in line with Katz and Martin (1997), who explain that experimental and applied research tend to be more collaborative.

Based on the reasons to collaborate presented by the Royal Society (2011), it is worth noting that some of them may also be related to the collaboration level. For example, "Decrease of error possibility" and "Increase of science expertise and Possibility of 'attacking' major research problems" are more characteristic in international collaborations, generally motivated by cognitive proximity, according Boschma (2005). "Physical need of working close to others, for friendship and pleasure of being with someone you like" and "Sharing the enthusiasm for research with someone" are related to reasons for intra-institutional collaboration, motivated by social proximity. "Achieving or expanding financing, resources, special equipment and materials" and "Desire to carry out multidisciplinary research" are more characteristic in inter-institutional collaborations and can be related to organizational proximity. However, scientific activities are self-organizing in response to knowledge frontiers and researchers seek collaborators who can contribute to advancing their research whether they are co-nationals or not (Leydesdorff et al. 2013).

In this sense, when analyzing different scientific fields, we verify that it is necessary to take into account all the specific typical aspects of each field, since dissimilarities among them can be very remarkable, starting with the nature of the research. In general, research in the Dentistry field is characterized by experimental studies and comprises the branch of applied sciences. We should emphasize that the development of applied science research requires greater dedication in laboratory studies and investment of material and economic resources. For Katz and Martin (1997), collaborative research is particularly common in experimental research, once the nature of this type of research involves the use of large complex instrumentation, such as telescopes, particle accelerators, etc. In addition, the economic benefits are obvious and the formal division of work is necessary in most cases. On the other hand, research in the Mathematics field is more theoretical, because it is a basic and pure science, characterized by studies dependent on deductions and defended theses, without concern for practical applications.

The "Sharing of enthusiasm for a research with someone" presents close and relevant values in the fields of Information Science (50%) and Mathematics (69%) and it is a less frequent motivation among PQ1 fellows in Dentistry (33%). However, the values identified for the "Physical need of working close to other researchers, for friendship or pleasure to be with someone you like" are significant for IS (40%), but not for the other fields, especially for Dentistry (5%). We consider that these motifs tend to be characterized by affinity relations, usually defined autonomously. In these cases, it is understood that collaborators are chosen in a self-organizing way, without the influence of other individuals, political and economic interests, or pre-established structures.

Katz and Martin (1997) consider that, even if some factors motivate more than others, collaboration is an intrinsically social process and, as in any human interaction form, can be motivated by many factors at the same time, especially when the number of individuals involved is greater, as in Dentistry. However, it is noteworthy that only four categories, "Decrease of error possibility", "Achieving or expanding financing, resources, special equipment and materials", "Desire to carry out multidisciplinary research", and "Need for external opinions to confirm or evaluate a problem" presented statistically significant difference among the fields. Therefore, the observed differences can be generalized to respective origin populations of these categories. For the other categories, the observed differences correspond just to the studied samples of the fields.

While analyzing the scientific production of the respondents of the questionnaire, we identified the predominance of scientific papers among the documentary typologies present in the scientific production of the three fields analyzed, namely: 83% of the production in the scientific field of Mathematics, 79% of the production in Dentistry, and 44% of the production in Information Science. We note that the field of Information Science is the one with the greatest balance in the typologies used by the PQ1 fellows in the dissemination of generated scientific knowledge, except for complete books.

The complete works in Annals of Events appeared as the second typology most used by the researchers in the three fields. As there is a general tendency of authorship types in the analyzed publication vehicles, we chose to group them in the general category called scientific production.

Table 7 presents the authorship type present in the fellows' scientific productions, in the period 2010–2012. The double authorship corresponds to the highest percentage of the publications of the Information Science field that, added to triple authorship, amounted to more than 65% of the publications. This result is close to Mena-Chalco et al.'s study of Brazilian Social Science. However, individual publications are quite significant in this field. In this context, when analyzing the PQ1 researchers' responses, an inconsistency is observed in relation to the author number that potentiates scientific production, since only one researcher stated that his/her research was mostly published in individual form.

As in IS, double and triple authorship is the most recurrent in the Mathematics field, found in more than 60% of its scientific production. On the other hand, individual authorship is less frequently represented in this field, which indicates that although the Mathematics field is a basic science and mostly characterized by more theoretical studies, which could indicate less dependence on collaborative activity, the co-authorship practice is usual among most of the PQ1 researchers who have answered the questionnaire. In addition, all PQ1 researchers from the Mathematics field worked in co-authorship in the period (2010–2012), according to their scientific production. We can find close results in the Glänzel (2003) and Mena-Chalco et al. (2014) studies.

For the Dentistry field, the most recurrent authorship type is the 6-authors, which when added to 5 and 7 or more authors amount to about 76% of its scientific production. Also, individual authorship corresponds to only four of the total of 1156 publications and is, therefore, quite rare. We see that researchers in the Dentistry field followed the trend of the answers given in relation to the number that potentiates scientific production and the number of coauthors and collaborators in their research (Tables 4, 5 and 6), by grouping 4

Table 7 Authorship types at PQ1 researchers' publications, by field (2010–2012)

Authorship types	Publications[a]					
	IS	%	Dentistry	%	Math	%
Individual	58	22.4	4	0.3	16	10.9
2 authors	114	44.0	28	2.4	46	31.3
3 authors	56	21.6	61	5.3	45	30.6
4 authors	27	10.4	183	15.8	30	20.4
5 authors	03	1.2	296	25.6	07	4.8
6 authors	–	–	334	29.0	03	2.0
7 or more authors	01	0.4	250	21.6	–	–
Total	259	100	1156	100	147	100

[a] Publications: papers, books, book chapters and complete works in Annals

and 5 authors/collaborators, and, thus, suggesting cohesion between understanding about the collaborative activity and the collaborative practice.

In summary, based on the analysis of the publications of the research participants, the three analyzed scientific fields present different behaviors regarding the knowledge production process and interaction with the scientific community, reflected in their research results. We note that there was a small, general deviant tendency in each field, both in the answers and in the scientific production, for the collaboration process, which indicates that there are social norms and rules within these communities that influence and guide the scientific behavior of their members as the *habitus*, idealized by Bourdieu, and the influence of cultural norms presented by Merton (1973). Different behaviors were identified among researchers from the same field, as well as some similarities among researchers from different fields, which evidence the influence of cognitive rules, highlighted by Kuhn (1962), on the scientists' conduct, that is, the predominance of the researcher perspective as an individual social actor. This argument refers to the idea of the autonomy of science and the self-organization present in the scientific collaboration process in a way that, although there are specific behavior patterns and central elements that guide the organization, the choice process is seen as autonomous, since the interaction is not always oriented by a central element.

Conclusions

From the analysis of the answers of the PQ1 fellows from the three scientific fields, we tried to answer the questions initially proposed. We observed that the collaborative behavior of Brazilian researchers is variable among the fields and close to other results found by researchers in studies in mainstream science. The number of co-authors in the Mathematics field in Brazil (2 and 3 co-authors) and the number identified by Glänzel (2003) (1 and 2 co-authors) were close when analyzing international science and close to the average number (2.2) identified by Beaver and Rosen (1978) for the field of physics. Additionally, where Glänzel (2003) found six co-authors to be most common for the Biomedical Sciences field, we encountered similar values for the field of Dentistry (5 and 6 co-authors), both fields in the biological sciences.

The researchers' perspectives on scientific collaboration are close to those found in the literature as well as those concerning the difference between the terms collaboration and co-authorship, collaboration types, main collaborators, and motives that drive collaborative behavior. We emphasize that there is a certain regularity in the behavior of the researchers within the analyzed scientific fields, which indicates that collaborative behavior tends to be more variable among the fields, rather than changing in different social contexts, which highlights the autonomous characteristic of Science, in which the system is self-organized and, although it is affected by social context, it does not interfere with its structure.

From the analysis of the publications of the PQ1 fellows, we can say that there was a small, general deviant tendency in each field regarding the types of authors identified. The average number of authors per publication in the Information Science field is 2.2 and in Mathematics is 2.8, whereas for the field of Dentistry the average was 5.3 authors per work.

For the three fields analyzed, the terms "Scientific Collaboration" and "Co-authorship" are considered terms that designate distinct activities, except for five Mathematics researchers and seven Dentistry researchers who consider them synonyms.

We see particular co-authorship behaviors in the three fields studied: In the Dentistry field, there is a tendency for grouping 4 and 5 co-authors; in Mathematics there are more publications in double authorship, as well as in Information Science, evidencing the autonomous characteristic of the field, which can also be influenced by the nature of the research. We observe that there is no complete congruence between concept and practice of collaboration, once inconsistent answers were identified within the results obtained in the analysis of the scientific production of some researchers in the three fields.

The preference for collaborative work with graduate students in Information Science evidences the presence of the organizational proximity dimension in this field, because the researcher-student relationship is hierarchical. In addition, institutional proximity is a strong dimension in this field, because among the main collaborators indicated are professors from other Brazilian institutions as well.

Organizational, institutional and geographical proximities are more noteworthy in the Dentistry field, since graduate students and professors from the same departments were highlighted by participant researchers. In Mathematics, cognitive proximity is the most remarkable dimension, because collaborative work usually takes place mainly with researchers from foreign institutions.

In this study we observed that "Desire to increase scientific popularity, visibility and personal recognition" was a seldom highlighted reason for collaboration by the researchers from the three analyzed fields, although it is usually mentioned in literature as a significant reason for collaborative work. We consider that this outcome difference may be due to the fact that the researchers participating in this study already have visibility and personal recognition in their respective scientific fields, since they comprise the Brazilian scientific elite (PQ1researchers).

Although Information and Communication Technologies have provided favorable conditions for knowledge production between geographically distant researchers, domestic collaboration was highlighted as the main collaboration type in the Information Science and Dentistry fields. This behavior follows the scientific literature tendency, according to which it is expected that spatial localization influences the interaction among researchers, since progress of research activities usually requires face-to-face communication through meetings and discussions among the collaborators (Pan et al. 2012; Sidone et al. 2016).

In Glänzel et al.'s (2006) study among Latin American countries, Brazil had the least international collaboration and presented a decrease in this collaboration mainly in the 1990s (Royal Society 2011). However, it should be noted that the results of this study showed the Mathematics field did not follow that general Brazilian scientific behavior tendency in the period analyzed (2010–2012).

We conclude that the Brazilian research elite in the Mathematics, Dentistry, and Information Science fields constantly collaborate in the knowledge production process and that co-authored publications are common in all three fields. We should take into account that individual authorship still presents significant value in the Information Science field, although most of the publications analyzed have been co-authored in this field.

Finally, it is necessary to analyze the researchers' collaborative behavior in the different fields and verify the distinct aspects related to the nature of the research, such as epistemology in the Mathematics, Information Science, and Dentistry fields in Brazilian science and the necessities of each study and consequent discussion on the validation form of the results, as well as the manner of task division to reach the research objective, and so on. It is, however, not possible to disregard the researcher's individuality in his/her scientific activity, which can generate deviations in relation to the general tendency of the analyzed field.

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