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Egocentric cocitation networks and scientific papers destinies

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Abstract

To what extent is the destiny of a scientific paper shaped by the cocitation network in which it is involved? What are the social contexts that can explain these structuring? Using bibliometric data, interviews with researchers, and social network analysis, this article proposes a typology based on egocentric cocitation networks that displays a quadruple structuring (before and after publication): polarization, clusterization, atomization, and attrition. It shows that the academic capital of the authors and the intellectual resources of their research are key factors of these destinies, as are the social relations between the authors concerned. The circumstances of the publishing are also correlated with the structuring of the egocentric cocitation networks, showing how socially embedded they are. Finally, the article discusses the contribution of these original networks to the analyze of scientific production and its dynamics.

1 | INTRODUCTION

This article aims to contribute to the analysis of the social dynamics of science by postulating that each particular scientific article may be part of the transformation of the scientific community within which it emerges and develops. What dynamics of science does this perspective reveal? What are the social conditions that explain the varying dynamics?

The social dynamics of science is an old and broad research topic and a lot of works have shown how scientific knowledge is embedded in social contexts at different stages of the scientific process. Studies focus on the general history of a discipline or specialty and show how transformations have occurred historically, emphasizing "paradigms shifts" (Kuhn, 1970) or the genesis of "thought collectives" (Fleck, 1981), the exponential transformation to "big science" (de Solla Price, 1986), or the "fractal distinctions" of disciplines (Abbott, 2010). But, because they want to explain historical change of scientific knowledge, these studies pay little attention to the actors and their personal contributions. Other studies focus on researchers and interpret their scientific trajectories in relation to their migrations (Mulkay, 1974), or their social interests (Barnes & MacKenzie, 1979). Still very actual, the work on researchers' careers no longer focuses on the community but rather on the professionalization of researchers (Laudel & Gläser, 2008). There are also well-known studies that address the immediate situation and show how each moment of the scientific process is a "manufacturer" of knowledge (Knorr-Cetina, 1981), showing how science is constructed, from the "laboratory life" (Latour & Woolgar, 2013) to "academic judgments" (Lamont, 2009). But in doing so, these do not capture changes at the scale of community structure.

Thus, the question of how scientific knowledge produced on an individual scale can have an impact on a

wider intellectual community remains to some extent unanswered. Social network analysis is particularly relevant to explore this articulation because it allows for the tracking of social relationships at multiple scales. Some of the earliest works that have addressed this issue have shown how a discipline is historically institutionalized as a result of the common interests and interactions of a few researchers (Mullins, 1972), and how the development of research specialties is partly supported by friendship (Michaelson, 1993).

Actually, many studies focusing on the scientific communities and they use network analysis to understand their configuration, emergence, or transformation. In these works, there is a lot of interest in the question of the spread of new ideas (knowledge) trying to explain why communities develop or decline (Ahajjam et al., 2018). Many of these works are based on the hypothesis of the influence of individuals who are in a central position (as hubs) in networks. While these works show how a structurally advantageous position can give power within a community (and sometimes ensure its future), it is not clear whether social characteristics of the individuals can explain the differences between situations. Are the advantages the same in all social circumstances?

In the sociology of science, the question of inequality between researchers has been a long-standing problem. The early investigations by Merton on the "Matthew effect" (Merton, 1968) and stratification of science (Cole & Cole, 1973) highlighted the contextual (university prestige, researcher trajectory, demographics) and cumulative effects on researcher productivity and visibility (citations). These sociological analyses are still ongoing and inequalities between researchers are identified, especially with regard to differential resources (personal, institutional, etc.).

To sum up, sociologists of science succeed in finding social factors that explain why some researchers are in socially dominant positions in science but, except cumulative effects and stratification, they do not say what these inequalities produce at the more structural level of communities. On the other hand, analyses of scientific communities highlight the emergence of social forms such as density or hierarchies between researchers but do not (or cannot) give a social dimension to these structural forms.

In this article, we argue that the perspective of egocentric networks can provide a new look on the dynamics of scientific communities and conciliates the two approaches: analyzing individual social positions and connecting them to broader community dynamics. To this end, we suggest that researchers transform scientific communities through their citation practices. We postulate that choosing references, citing authors is not only an intellectual act but also a social act (Cronin, 1984; Frickel & Gross, 2005). We will consider egocentric networks through micro-cases—i.e., on the basis of a single publication—and examine the change in the scientific community that it involves and in which it is embedded. In doing so, we capture dynamics that are invisible when studying communities at the broader level, and suggest that each case has to be understood within a larger social framework.

The central questions are whether there are specific dynamics captured by the egocentric point of view and what are the social conditions that support those particular changes in the concerned community?

The article uses several methods that combines bibliometric sources, interviews with researchers and network indicators. Based on 102 case studies of scientific articles, the approach is to (a) capture the dynamics of the scientific community surrounding a given scientific publication (its egocentric cocitation network); (b) consider the social conditions of emergence of the papers; (c) compare and analyze the various dynamics.

After explaining their construction, we will present the main characteristics of the egocentric cocitation networks and the structural indicators chosen to explain them. We will propose a typology that considers their particularly and diversity according to their structural transformations, showing that they occur in particular social contexts.

Before presenting our results, we will discuss how our approach fits in with other works addressing the dynamics of scientific communities and social conditions of science.

2 | EGOCENTRIC NETWORKS AND THE DYNAMICS OF SCIENTIFIC COMMUNITIES

In social studies of science, egocentric networks of researchers are often considered as indicators of prestige and attractiveness or a sign of their ability to find supports and resources for their activities (Bozeman & Corley, 2004; Lee & Bozeman, 2005). A personal network, as a social/academic capital, is an indicator of the capacity of researchers to find support for their activities or careers (cf., Karlsson & Wigren, 2012; Pezzoni et al., 2012). Reference can be made here to the long-standing work of the sociologist (Zuckerman, 1977) on scientific elites, which shows the cumulative advantages of social capital during the careers of researchers.

Other studies explore the scientific literature to find similar patterns. In their most radical form, they measure the prestige and attractiveness of an individual researcher with bibliometric indicators such as the author impact factor and author's h-index (the number h of publications cited h times). Among these bibliometric works, collaboration has been explored through the study of the ϕ-index (the number ϕ of publications with ϕ different collaborators for an author) whose main result is its matching to the h-index (Cabanac, 2013). These works do not focus on structural issues but rather aim to explain the individual performance score (bibliometrics) of researchers (Abbasi et al., 2011).

Some works specifically highlights the structural features of coauthorship (Glänzel & Schubert, 2004). Focusing on large samples of publications, they show how some researchers or groups of researchers are vectors of attraction within the networks (forming "hubs") that contribute to structuring the network according to the "preferential attachment model" (Barabási et al., 2002). However, these works remain very wide-ranging since their objectives are often to establish models that account for the dynamics of self-organizing scale-free networks (Lemarchand, 2012) through the study of large corpus of publications and coauthorship. The social dimension is not always fully reflected in their models and formalizations, particularly at the actors' level.

For their part, sociologists of science have long been concerned with the importance of exchange and relationships in order to understand the scientific community (Hagstrom, 1966). Since the "invisible colleges" (Price & De Beaver, 1966), the "social circles" (Crane, 1969), the "Actor Network Theory" (Latour, 1987), and "epistemic cultures" (Knorr-Cetina, 1999), it is known that scientific communities do not strictly correspond to the institutions which organize them, and that interpersonal relationships are also important and structuring factors. But, except Crane (1969), these pioneering studies did not develop social network analyses.

In recent years, some work has investigated the impact of researchers' interpersonal relationships on the structure of science. Lazega et al. (2008) pointed out the organizational factors associated to relations to explain hierarchical positions of researchers. Gonzalez-Brambila et al. (2013) show how the structural position of researchers (in particular their centrality and position in relation to structural holes) explains their pre-eminence. Villanueva-Felez et al. (2013) question the personal networks of researchers and compare the distribution of strong and weak links (according to degree) to understand the performance of researchers. Cabanac et al. (2015) show the progressive trend towards homophilia in coauthorship across individual careers. Martín-Alcázar et al. (2019) emphasize the importance of interpersonal (rather than cognitive and structural) relationships for team cohesion.

As seen, researchers' egocentric networks affect their social capital, their attractiveness and the structuring of their professional groups. Are they also linked to their scientific production?

An early trend in the sociology of science (Small & Griffith, 1974) uses the scientific literature and citations to show how their structure (networks of cocitation) reveal specific "research areas" and their changing (Small, 1977). More recently, the broad field of community detection studies has seen the development of work on science that uses network analysis to understand the mapping, emergence, or transformation of scientific specialties and communities (Chen & Redner, 2010; Perianes-Rodríguez et al., 2010). The objective is to identify structural criteria that show that parts of the community are more cohesive and distinguish them from each other. These studies do not explore how demarcations between communities occur, nor what social mechanisms may cause or sustain them. The scientific literature is seen as a structure in itself, whose structural configurations must be described, including its dynamics (Chakraborty et al., 2014).

To explore these social mechanisms, others studies show that the knowledge structure is not independent of the social structure. Wallace et al. (2012) suggest that citations between authors are more frequent between those who are structurally close in the network of coauthors. Few years before, Perry and Rice (1998) have studied the relationships between social structure (interactions) and intellectual structure (cocitation). They show a system of stratification within the intellectual structure that would suggest the impact of social status on the intellectual structure. More recently, Shwed and Bearman (2010) understood the scientific consensus by analyzing cocitation in the literature, with the hypothesis that it is controlled by referees. Roth and Cointet (2010) aim to identify epistemic communities by examining collaborations and concepts (words used) through a set of papers of a group interested in the same topic. These analyses provide features of the links between the social network (the act of coauthoring a paper) and the cocitation networks (the act of citing the same references). However, few of them consider the social dimension contextualizing the act of citing.

Smaller-scale works have shown that social structure (personal relationships) is reflected in intellectual structure (bibliographic references), (Rowlands, 1999). Since the early work on "invisible colleges" (Crane, 1972; Price & De Beaver, 1966), it has been pointed out that acquaintances and friendships coincide with bibliographic references. Later, a hypothesis has been developed which

proposes that intellectual and social networks are non-exclusive, overlapping one another, arising from one another (Johnson & Oppenheim, 2007; Milard, 2014; Milard & Tanguy, 2018; White et al., 2004). In these works, citations are seen as mirrors of the social structure, but also as visibility indicators of invisible colleges and an opportunity to maintain relationships between researchers. Citations are seen as one of the mechanisms of transforming scientific communities and they have the advantage of being capturable at both the individual and community levels.

In this paper, we will consider citations as a micro-mechanism that transforms scientific communities. The dynamics of scientific knowledge are captured through an analysis of the transformation of cocitation networks and studied from an egocentric point of view. We consider egocentric networks in a different way from the individual and strategic analysis, privileging a study of the scientific community in which the scientific article and its author are involved. The challenge of the article is also to identify social mechanisms on a fairly small scale, as well as to place them in a broader context. Thus, this article contributes to the general question of the social conditions under which scientific communities are transformed by providing a micro-social and egocentric network perspective on these dynamics.

We now present the method we have applied.

3 | MATERIALS AND METHODS

The methods used are described in the following subsections. First, we describe the panel of 102 articles and 58 researchers interviewed (section 3.1). Second, we explain the design of the egocentric cocitation networks of the 102 publications and the measure of their evolution using structural indicators (section 3.2). Third, we present the gathering of indicators concerning the intellectual and social context of the publication of the articles (section 3.3). Finally, we expose the tests used and the analyses performed (section 3.4).

3.1 | Description of the panel: Articles and interviewed researchers

The present study is based on a panel of 102 publications in biology, mathematic, economics and sociology.

To constitute the panel, the choice was made to diversify the disciplines investigated: natural sciences and social sciences; experimental sciences and theoretical sciences. Interviewed researchers belonging to four disciplines or subdisciplines: molecular biology, mathematics, economics, and sociology. To have better conditions for our studies, we have chosen disciplines with a limited number of coauthors and references (avoiding physics for example).

To select authors to interview and their publications, we have used the Web of Science (WoS) published by Clarivate®, one of the most well-known and widely used bibliographic databases. So, all articles had been published in highest-quality journals.

The publication selection criteria were as follows: (a) the interviewed author must be tenured; (b) the author must be a member of a certified laboratory in his field; (c) he or she must have published at least two articles as corresponding author (or reprint author) within a period of 5 years; (d) each of the articles have at least 15 references; (e) in the situation where several articles matched the criteria, the most cited were selected; (f) the author have accepted the face-to-face interview.

The 102 articles of the corpus were published between 2005 and 2010 (86% are between 2007 and 2009) by 58 different authors. Almost all the authors were interviewed about two of their articles; but in some cases ($n = 14$), it was impossible because the researcher did not have enough time for the interview. All in all, we have collected a sample of 33 articles in economics, 27 in biology, 23 in mathematics, and 19 in sociology. Fourteen articles are published in French: 3 in economics and 11 in sociology; the others are published in English. The 102 studied articles are typical of French articles published in renowned journals (according to the criteria of the WoS database).

The 58 interviews were conducted in 2012 and 2013 and they took place in several French cities (Toulouse, Paris, Marseille, Poitiers, and Tours). They were conducted by four different interviewers, mainly in the authors' offices, and lasted between 1 and 3 h each (total duration of over 100 h).

The interviews addressed the author's trajectory, the history of the paper and relations with others authors. The questions were the following. Where did the idea for the publication come from? Does it follow on from other publications or is it a change in the authors' trajectory? What collaborations? How did the submission occur? What has been the posterity of the article? Additionally, questions were asked about the authors cited in references and the authors who cite the same references (see section 3.3 below for details).

3.2 | Building egocentric cocitation network of each article and measuring their changing

First of all, using the WoS, we have collected all publications that share at least three references with each of the

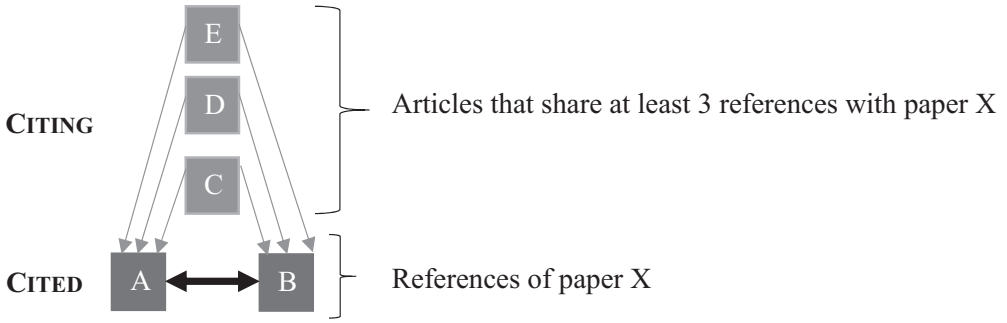

FIGURE 1 Egocentric cocitation of paper X (adapted from Garfield, 2001 cocitation schema)

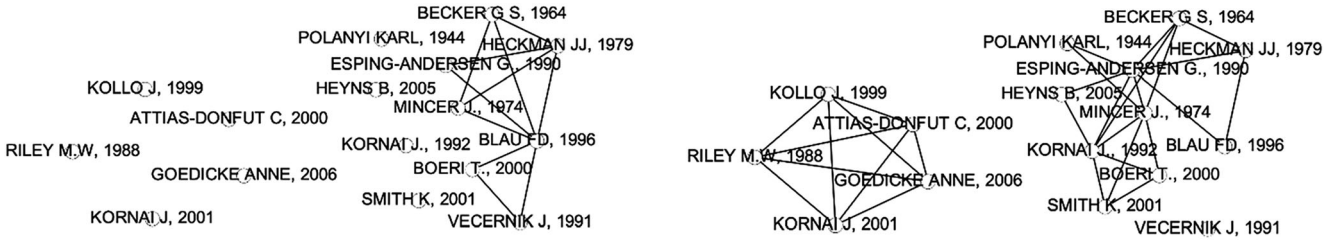

FIGURE 2 Example of the dynamics of an egocentric cocitation network: before and after the publication of the article studied

articles under study ($n = 102$). We have set this cut-off point in order to keep only those articles that are closest to the concerned article. The average size of the reference sets is 167; the 25th percentile is 57; the median is 112 and 75th percentile is 223.

Then, using each of these sets, we built the egocentric cocitation network of each of the 102 articles. A cocitation network is an appropriate way to examine how knowledge is combined in scientific research work (Small, 1973). We have fitted this method to the egocentric analysis we want to undertake.

As describe in Figure 1, articles A and B cited by paper X are associated because they are both cited in the reference list of C, D, E that share at least three references with paper X. Nodes of the network are the research papers cited by the article X and they are associated if at least one other article of the set cites them together. Obviously, the studied article is discarded for the link construction of the network since considering it associates all the nodes. This cocitation network enables to represent how the knowledge mobilized by the studied article has been mobilized by other intellectually close articles.

Since our goal is to study the evolution of a scientific community around a specific article, we extend the network by a temporal dimension. In case of an egocentric cocitations network around a paper X, the publishing date of the paper X is decisive and determines a "before" and an "after." So, two-time intervals, before and after the publication date of the studied article, are defined to construct the cocitation coupling links. Although there are specificities in terms of disciplines, we have opted for identical intervals in order to be able to compare the results. The first-time step of the cocitation coupling network represents the 5 years that preceded the publication of the studied article. The second time step represents the year of publication of the article studied and the following 4 years. If a node is isolated during all the period, we have removed it from the network because we consider that it does not contribute to the dynamics we are trying to understand.

Let us illustrate the construction of the egocentric cocitation networks with the example of a sociology paper published in 2009 (cf., Figure 2).

Figure 2a shows the first period, that is, 2004–2008 and Figure 2b the second, that is, 2009–2013. Although there are 33 references in the article, 17 were never cited in conjunction with any of the 33 references during the studied period. Thus, only 16 references constitute the set of nodes. For example, there is no link between the references [Kornai, 2001] and [Riley, 1988] in Figure 2a because there is no article published between 2004 and 2008 that cites these references jointly. Conversely, the link exists in the second period. Even if they are cited most of the time by other authors, the main author himself may have cited the same references in later articles, showing that the place of the author himself in these egocentric cocitation networks is interesting to study.

How to seize the evolution of this network between the two periods considered? Two characteristics are

TABLE 1 Description of the 17 indicators used to characterize the scientific and social contexts of the 102 publications

Indicator	Type of variable	Description
1: discipline	Categorial	Discipline of the article: mathematics; biology; sociology; economics
2: number of contributors	Numerical	Number of authors of the studied paper (min = 1; max = 10)
3: number of references	Numerical	Number of references of the studied paper (min = 10; max = 70)
4: age of references	Numerical	Age of each references (calculated with respect to the year of publication of the article studied) (min = 0; max = 196)
5: number of cited names	Numerical	Number of cited names of each reference (min = 1; max = 42)
6: number of citations obtained	Numerical	Number of citations obtained by the article (5 years after the publication) (min = 0; max = 62)
7: gender	Categorial	The gender of the main author of the article being studied: woman; man
8: seniority of the main author	Numerical	The level of expertise of the main author of the article under study according to the year of his/her PhD graduation (calculated with respect to the year of publication of the article studied) (min = 4; max = 46)
9: knowing the authors cited in the references of his/her paper	Verbatim coded in categorical	Typical interview extracts and categories: • **Knows all** cited authors in the reference "*This is my team, so I know everyone*" (biologist); "*he is a great specialist of X. M. is his former student. I know them both quite well*" (mathematician) • **Knows some of** the cited authors in the reference: "*I don't know these two, but I know the leader, P., who is a competitor*" (biologist); "*I don't know the first two, but I know S., a colleague and professor of sociology*" (sociologist) • **Knows none** of the cited authors in the reference: "*This is the same, no knowledge, it is purely bibliographic*" (economist); "*I think it was something I had read... I don't remember more*" (sociologist)
10: ratio of authors in the egocentric coauthor network	Numerical	The ratio of authors of the article studied as nodes in the coauthors network (min = 0; max = 1)
11: centrality of the main author in the egocentric coauthor network	Numerical	Centrality Katz of the main author in the coauthor network (min = −1; max = +0.425)
12: number of articles in the egocentric cocitation network	Numerical	Number of articles citing at least three articles in common with the article under study (over the entire study period) (min = 11; max = 802)
13: ratio of articles published during the last 5 years in the egocentric cocitations network	Numerical	Ratio of articles citing at least three articles in common with the article studied published in a window of 5 years, centered around the year of the article's publication (min = 10%; max = 74%)

TABLE 1 (Continued)

Indicator	Type of variable	Description
14: ratio of international articles in the egocentric cocitations network	Numerical	Ratio of articles citing at least three articles in common with the article studied according to the geographical area where the main author works (window of 5 years). The areas considered all of the world excepted France (min = 0%; max = 100%)
15: ratio of articles from another discipline in the egocentric cocitations network	Numerical	Ratio of articles citing at least three articles in common with the article studied (window of 5 years) according to the disciplinary proximity between the article studied and the citing article, based on the disciplinary coding of the journals (source WOS). The levels of proximity considered is strictly different (min = 0%; max = 96%)
16: comments on the authors who form the core of the egocentric cocitation network of the paper	Verbatim	Typical interview extracts: "*It's obvious: we can see the groups: the Spanish, the French and the Belgians, those are the Swiss...*" (biologist) "*She completed her PhD in Louvain, I was a member of her jury and he's her co-author. I met him, we invited him for a workshop. He's a Spanish economist who also worked with J., by the way*" (economist)
17: detailed description of the publishing context	Verbatim	Transcription of the part of interviews describing the circumstances that motivate or led to the publication

particularly relevant for determining the dynamics of a community: its vitality and its structuring (Crane, 1969; Newman, 2001). We have used two well-known global metrics in network analysis: density and modularity. Indeed, the denser a cocitation network, the more the publications have been jointly mobilized, attesting the vitality of the scientific community under study. Also, modularity is a well-known measure to quantify the quality of a community partitioning (Blondel et al., 2008; Newman et al., 2006). Therefore, the modularity of a partitioning obtained using one of these algorithms can be used as a proxy to capture the structure of a network into structured subcommunities (clusters). We therefore use this methodology to evaluate how each scientific community is structured. We thus calculate the delta of the density and the delta of the modularity between the two periods for each egocentric cocitation network.

To sum up, we started by extracting from the WoS the list of articles that share at least three references with the article under study. Then we built the egocentric cocitations network of each paper under study. To characterize the 102 egocentric cocitations networks, we used two structural measures, density and modularity and identify their evolution over time—5 years before and 5 years after the publication of the article—in order to have a proxy of the vitality and structuration concerning the scientific community surrounding the article under study.

3.3 | Characterizing social contexts of the publication

In order to understand the social context in which the articles appeared, we characterize the authors, publications and bibliographical references involved in the analysis. A detailed description of the indicators describing the scientific context is provided in Table 1.

First, the articles studied are described using elementary indicators, for example, discipline, number of authors, and some bibliometric indicators such as the number and age of its references, the number of citations obtained (cf., indicators 1–6).

Next, we collect and compute a set of indicators specific to the authors of the article under study (principal author). In addition to the gender of the corresponding author, data sources from CV are used to determine their seniority: what is the age of the author's PhD that defines his/her entry into academic life? (cf., indicators 7–8).

Next, we measured their personal implication in the studied article. During the interviews, we asked whether

the researcher interviewed knew the authors cited in their bibliographic references. Based on the 58 transcribed interviews, all responses for each 3,434 references cited in the 102 publications were then manually coded the information if they know all the authors of the reference, only some of them, or none (cf., indicator 9).

Then we capture the role of the authors of the studied article within the egocentric cocitation network. More precisely, the publications considered are all the publications that have at least three references in common with the article studied. The set of authors of these articles serves as a proxy to capture the scientific community of researchers working on topics close to the one considered in the article studied. Thus, the presence or importance of the interviewed researchers in this network can be indicators to qualify their expertise as well as their influence in the intellectual community (cf., indicators 10–11).

We also define a set of indicators associated with articles that have common references with the article under study. These indicators enable us to situate the article under study in the broader context of scientific production on the topic in question. Therefore, the number of articles citing common references, their age, their geographical and disciplinary origin are informative signs in this perspective (cf., indicators 12–15).

From the corpus of publications that cite at least three references common to the paper studied (see section 3.2), we select those close in time to the publication date of the article (2 years before and after) and represent them as a network of coauthors. During the interview, the network of coauthors intellectually close to him is presented to the interviewed researcher who answers the questions of whether and how he or she knows them (cf., indicator 16).

To complete the picture, we have collected excerpts from the 58 interviews that outline the social and intellectual circumstances that motivated or led to the publication (cf., indicator 17).

To sum up, we mobilized 17 indicators to characterize the 102 articles, 3,434 references and their 58 authors: 12 indicators as a numeric variable, 3 categorical variables, and 2 descriptions (verbatim).

3.4 | Tests and analyses performed

To conduct our analysis, we used three types of approaches, some purely quantitative, some purely qualitative, some mixed.

The data on which we chose to base our study are the 3,434 article references for two reasons. First, the 102 egocentric cocitation networks are constructed by the 3,434 references (see section 3.2); second, the contexts of the articles are grasped at the fine scale of these references on several occasions (cf., section 3.3). Thus, all the statistical analyses are based on the 3,434 references/relations. However, to avoid bias, we weighted them so that they have the same importance per paper (i.e., 33.67 references on average per paper).

To check whether the indicators are correlated with the evolution of the density or the evolution of the modularity, three different tests were performed depending on the nature of the variables (cf., Table 1):

- If the two variables are numerical, we calculate the Pearson correlation coefficient in order to test linear association.
- If one of the variables is categorical and other is numerical, we applied the *t* test of equality of means. It should be noted that these tests can be applied because we have previously ensured the normality of the data involved in these tests (Test de Kolmogorov–Smirnov).
- If the two variables are categorical, we applied the chi-square test of homogeneity and Fisher's exact test to calculate *p*-values between two modalities.

Some data are obtained on a qualitative basis. To analyze the circumstances of publication (see Table 1, indicator 17), we selected a subsample of 32 articles that were most representative of the dynamics identified, in order to carry out a more relevant qualitative analysis: 9 in biology; 9 in economics; 8 in mathematics; 6 in sociology. We used the same subsample of 32 articles to analyze the authors' comments on the egocentric cocitation networks (see Table 1, indicator 16).

To conduct the analysis, quantitative data were decisive. The articles were grouped into four specific types on the basis of indicators of their egocentric cocitation networks. Thereafter, the analysis of these groups beyond their structural characteristics was conducted through interviews with the principal authors. The approach consisted in interpreting the authors' statements by seeking out the similarities between the situations of publications belonging to the same group. Even if the number of cases remains small, the detection of similarities on such a precise scale ensures rather robust results. In doing so, this work is in line with the emerging field of mixed methods, particularly relevant in network analysis (Domínguez & Hollstein, 2014).

4 | RESULTS

The questions we want to answer in this part are the following. What are the dynamics of the egocentric cocitation networks surrounding scientific papers at the time of

TABLE 2 Pearson correlation coefficient between the numerical variables and the two indicators of the egocentric cocitation networks' evolution

	Delta density		Delta modularity	
Variables	**Pearson *r***	***p*-value**	**Pearson *r***	***p*-value**
2: number of contributors	0.019		**0.076**	***
3: number of references	**−0.179**	***	**0.182**	***
4: age of references	−0.001		**0.067**	***
5: number of cited names	**0.061**	***	0.021	
6: number of citations obtained	**0.204**	***	−0.001	
8: seniority of the main author	**0.067**	***	**−0.077**	***
10: ratio of authors in the egocentric coauthor network	**0.175**	***	**−0.054**	**
11: centrality of the main author in the egocentric coauthor network	**0.225**	***	**−0.039**	*
12: number of articles in the egocentric cocitation network	0.011		−0.030	
13: ratio of articles published during the last 5 years in the egocentric cocitations network	0.032		**0.082**	***
14: ratio of international articles in the egocentric cocitations network	0.002		**0.162**	***
15: ratio of articles from another discipline in the egocentric cocitations network	**−0.134**	***	**0.238**	***

Note: Significant correlations are in bold and the level of significance is indicated by the signs *$p < .5$; **$p < .01$; ***$p < .001$.

their publication, considering the structure of the scientific community in which they are involve? Are these dynamics linked to specific social positions, research practices, scientific and social contexts?

4.1 | Vitality and structuring of an egocentric scientific community

The objective of this section is to characterize the two indicators of scientific communities' evolution (from an egocentric perspective) to understand their contexts and overlap. We will start by describing the contexts according to the two main dynamics—density and modularity—and next we will present their overlap.

We have explained how egocentric cocitation networks have been constructed and how to capture their dynamics (see section 3.2). Let us consider the correlations that these two dynamics present with the characteristics of the articles, their authors and the articles intellectually close (cf., Tables 2 and 3). What are the significant tends and how interpret them?

As seen in Tables 2 and 3, the only variables that are not significant are the size of the egocentric cocitation network and the gender of the article's main author. All other variables are correlated to the evolution of density and modularity (according to the criteria presented in section 3.4).

The evolution of density tends to be positive especially when the number of citations received by the article is higher and when there are less references, but with more names cited in each. It also increases as soon as the presence of the main author is more central in the cocitation network. This is more likely to be the case for economists and not for sociologists. Finally, the increase in density is associated with a greater seniority of the main author. It can be inferred that the delta of density increases more when the article and its author are more powerful in term of citations, centrality and seniority.

The evolution of modularity tends to be positive when the number of contributors of the article, the references and their age are higher. This is truer for sociologists and for younger authors. Modularity increases especially when the references intellectually close to the article are more numerous, old, international, and interdisciplinary. It can be concluded that, when modularity increases, the scientific background is more complex from an intellectual point of view.

Delta density and delta modularity seem to be dependent on different contexts. The correlation between them presents is negative (p-value <.001), which means that when one is high, the other tends to be low and

	Delta density		Delta modularity	
	Mean	***p*-value**	**Mean**	***p*-value**
1a: biology	−0.005		0.004	
1b: mathematics	−0.015		**−0.038**	***
1c: economics	**0.017**	***	−0.005	
1d: sociology	**−0.079**	***	**0.042**	***
7a: woman	−0.011		−0.005	
7b: man	−0.015		−0.001	
9a: knows all the cited authors	−0.016		**−0.009**	***
9b: knows some the cited authors	−0.003		0.006	
9c: knows none of the cited authors	−0.018		**0.012**	***
All	−0.014		−0.001	

TABLE 3 *T* test between the categorial variables and the two indicators of the egocentric cocitation networks' evolution

Note: Significant correlations are in bold and the level of significance is indicated by the signs *$p < .5$; **$p < .01$; ***$p < .001$.

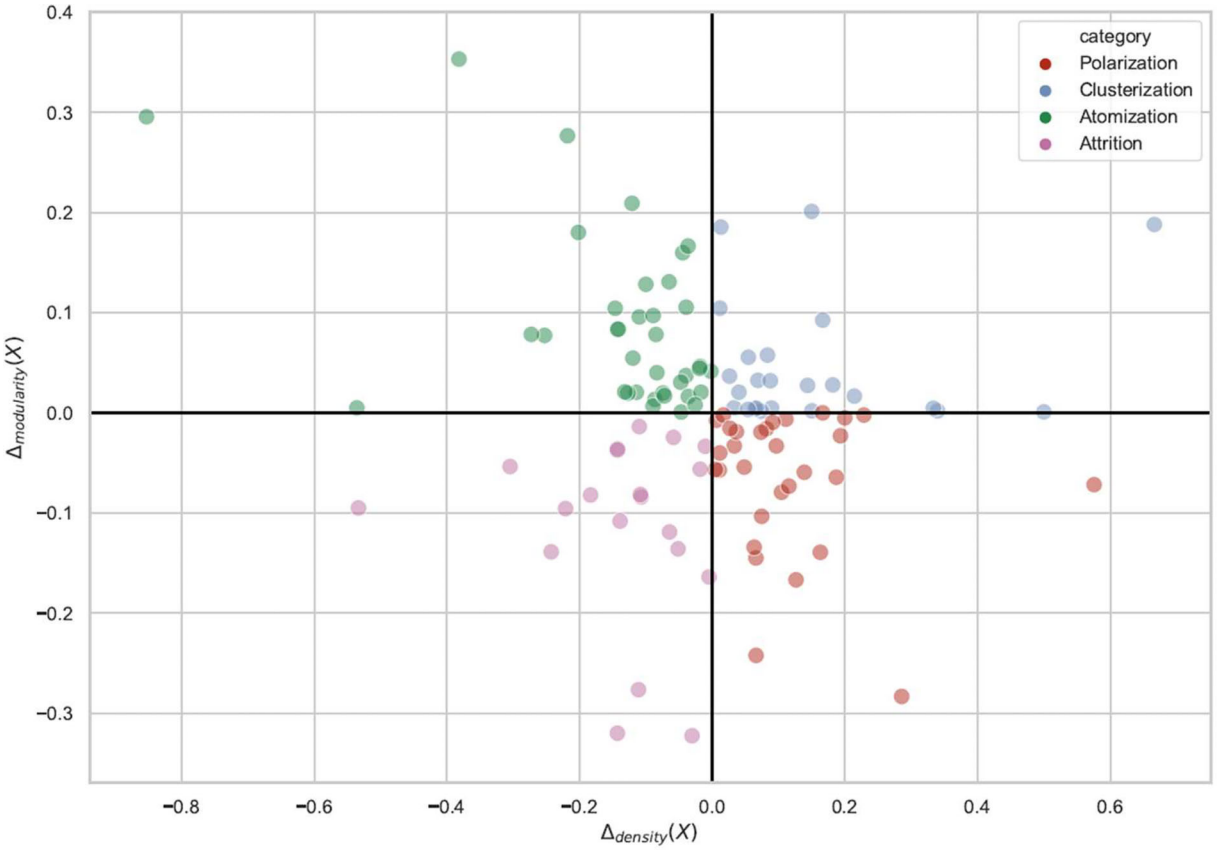

FIGURE 3 Scatter plot of the delta density (horizontal axis) and delta modularity (vertical axis) values calculated on the 102 articles

conversely. They shall be combined to give more precise information on the dynamics of the egocentric cocitation network (cf., Figure 3).

Figure 3 shows the scatter plot of delta density and delta modularity and presents the joint evolution of density and modularity for each article studied. The 102 papers can be subdivided according to whether the delta of density and/or modularity is positive or negative. Figure 4 summarizes the four cases that this leads to. As seen in Figure 3, some articles are particularly typical, while others are less significant. Nevertheless, they can be grouped together as one because they share the same

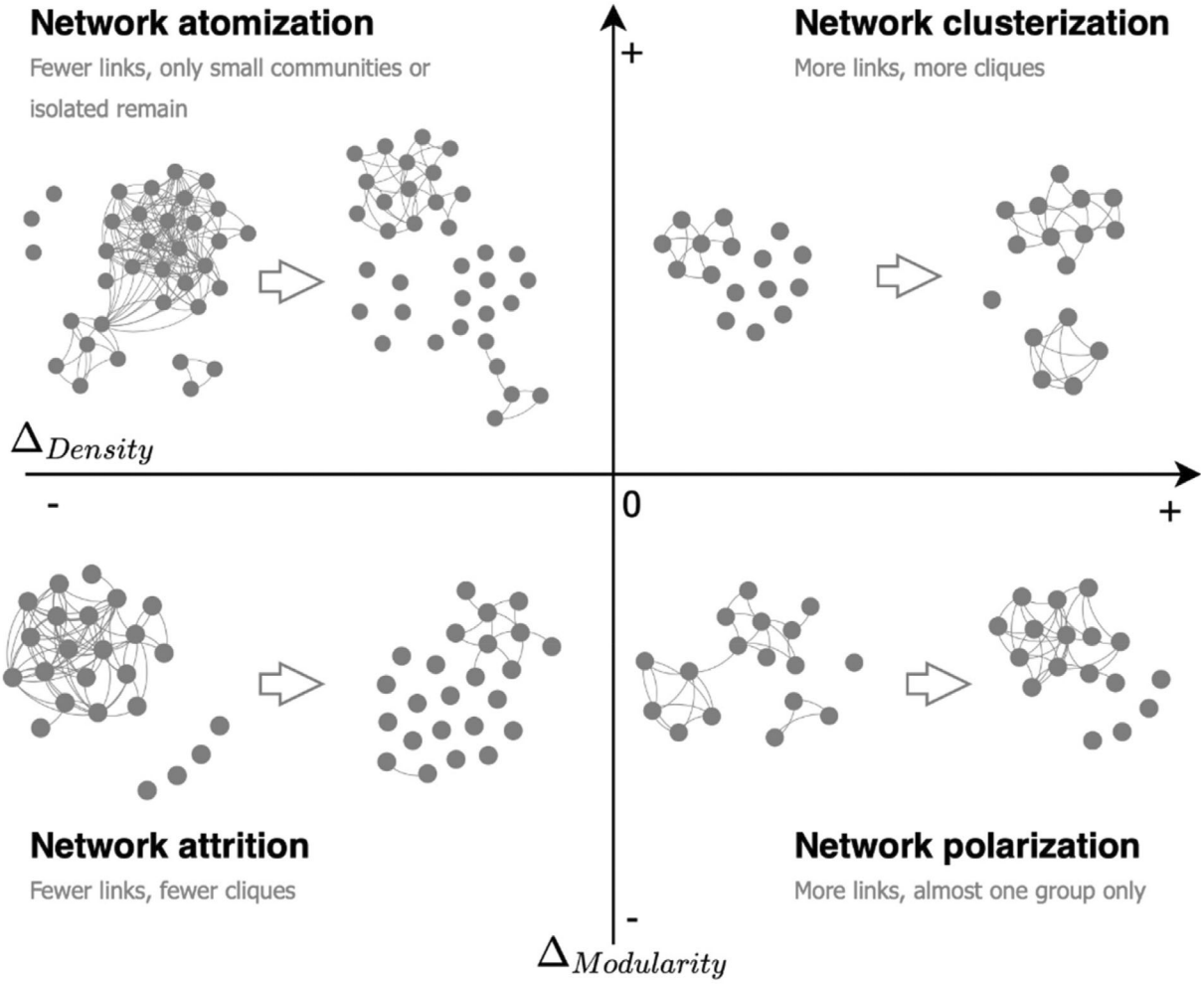

FIGURE 4 Typology of the egocentric cocitation networks according to the evolution of their density and modularity

dynamics (positive or negative) in terms of vitality and structuring of the communities surrounding them.

Networks with increasing density and modularity belong to the category called network clusterization (top right of Figure 4). In this category, the network may be relatively sparse and not really structured into communities. Thereafter, it is denser (more links) and structured into communities (more cliques). Networks with increasing density but decreasing modularity belong to the category called network polarization (bottom right of Figure 4). The network may be relatively low-density and is structured into well-differentiated and relatively large communities. Thereafter, it is denser (more links) and structured around one large connected component. Networks with decreasing density and increasing modularity belong to the category referred to as network atomization (top left of Figure 4). In this category, the network may be relatively dense and structured. Thereafter, it is less dense (fewer links) and only a part of communities remains. Networks with decreasing density and modularity belong to the category called network attrition (bottom left of Figure 4). In this category, the networks may be relatively dense and structured in communities. Thereafter, it is less dense (fewer links) and communities have disappeared. As in previous works on personal networks (Bidart et al., 2018), this typology will be used to compare the dynamics of egocentric cocitation networks by combining the two indicators (here density and modularity).

Tables 4 and 5 present the characteristics that are associated with each type of networks and the following four subsections presented the main results of the statistical treatments and qualitative analysis.

4.2 | Polarization: A capitalizing context

Network polarization means that the authors of the publication studied have mobilized knowledge that were rarely cited together before. Then, after the publication, the scientific community tends to unify into an indistinct and active group sharing more cocitations. What are the characteristics of this type?

TABLE 4 Mean and *t* test between the four categories of egocentric cocitation networks and numerical variables describing authors, articles, and references.

	Network polarization		Network clusterization		Network atomization		Network attrition		
	Mean	*p*-value	Mean	*p*-val.	Mean	*p*-value	Mean	*p*-value	All
2: number of contributors	**3.07**	**	**3.50**	*	3.37		3.20		3.28
3: number of references	**31.44**	***	34.40		**37.17**	***	**29.80**	***	33.67
4: age of references	**12.32**	**	12.80		**15.32**	**	13.65		13.70
5: number of cited names in reference	2.49		**2.84**	**	2.61		**2.20**	**	2.55
6: number of citations obtained	**10.74**	***	**13.85**	***	**8.03**	***	**5.10**	***	9.31
8: seniority of the main author	**22.93**	***	**20.65**	**	21.86		21.55		21.84
9: ratio of authors in the egocentric coauthor network	**0.62**	***	0.44		**0.39**	***	0.44		0.47
11: centrality of the main author in egocentric coauthors network	**−0.11**	***	−0.40		**−0.47**	***	**−0.50**	***	−0.37
12: number of articles in the egocentric cocitation network	**195.11**	***	**149.75**	**	**175.46**	*	**132.15**	***	167.13
13: ratio of articles published during the last 5 years in the egocentric cocitations network	40.22		**42.10**	**	**42.11**	***	**37.95**	***	40.79
14: ratio of international articles in the egocentric cocitations network	**76.27**	**	**80.05**	***	**78.02**	**	**74.70**	***	77.31
15: ratio of articles from another discipline in the egocentric cocitations network	**31.12**	***	**42.79**	***	**41.83**	***	**28.41**	***	36.55

Note: Significant correlations are in bold and the level of significance is indicated by the signs *$p < .5$; **$p < .01$; ***$p < .001$.

TABLE 5 %col. and Fisher test (Khi^2) between the four categories of egocentric cocitation networks and categorial variables describing authors and relations

	Network polarization		Network clusterization		Network atomization		Network attrition	
	%	*p*-value	%	*p*-value	%	*p*-value	%	*p*-value
1a: biology	25.9		**22.2**	*	37.0		**14.8**	***
1b: mathematics	**34.8**	***	**13.0**	***	**17.4**	***	**34.8**	***
1c: economics	**36.4**	***	**15.2**	***	36.4		**12.1**	***
1d: sociology	**0.0**	***	**31.6**	***	**47.4**	***	21.1	
7a: woman	**18.2**	***	**22.7**	*	**27.3**	***	**31.8**	***
7b: man	**28.8**	***	**18.8**	*	**36.2**	***	**16.3**	***
9a: knows all the cited authors	**28.0**	*	**17.2**	***	33.3		**21.6**	**
9b: knows some the cited authors	25.7		21.1		**38.0**	*	**15.2**	**
9c: knows none of the cited authors	**23.2**	*	**24.6**	**	34.0		18.2	
All	26.5		19.6		34.3		19.6	

Note: Significant correlations are in bold and the level of significance is indicated by the signs *$p < .5$; **$p < .01$; ***$p < .001$.

As seen in Tables 4 and 5, network polarization more often concerns economists or mathematicians, and not at all sociologists. There are significantly more men and senior researchers in this type. The number of references by article and their age are smaller. The cited authors are rather all known by the interviewed researcher and it is rarer that they are not at all.

In this type, the size of the egocentric cocitation network of articles is greater. Comparing to the others, it is not so international and interdisciplinary, but the authors are very well represented and the main author is particularly central. During the description of the egocentric cocitation network, the authors mention chains of ties, where they are central and where institutions (laboratories,

teams, journals...) connect the authors. An economist describes: "He was in my lab when I was at the CNRS, I know him very well. [...] She did her thesis in Louvain, I was on her jury. [...] We had invited him for a workshop." A biologist says "they are people from MD's team, who was in our team at the time; I know, R, he was at the Pasteur Institute a very long time ago. We're in a European vaccine network [...] So we see each other at least once a year." A mathematician comments: "it's someone I meet several times a year at conferences. [...] M and A, we had met during classes in California and afterwards at conferences. We've met again, and again... ." Relationships within the egocentric cocitation network are described like chains of ties that put the researcher in the center of them and/or involve institutions. These chains seem more robust due to these institutions involved and also to the uniformity of the network (discipline and country).

These articles are characterized by the position and weight of their author(s) in the intellectual and social network. What can explain this central position?

Articles that belong to this class are often publications that follow others in series of two or three. A mathematician indicates that his article is the result of "intermediate" work on harmonic sections (geometric topology) which will be extended later. An economist whose article discusses schooling cost presents his paper like a continuation of another. One of his colleagues specialized in pricing rules also insists: "it's a paper to stabilize the foundations of things that were said before." A biologist, specialist in protein biochemistry, said that his publication "was a continuation of all the work I had developed since the beginning" and his colleague, also a biologist but specialized in the sequencing of bacterial genomes, said that even if the result was rather unexpected at the time of publication, "it is something that is coming to an end...it was all slowing down." Even when they are no more current, the articles are not viewed negatively. This mathematician presents his article on geometric group theory as "a paper showing something that nobody cared about at the time, but now people are starting to understand that there is something a little strange, a little interesting going on."

These articles continue and complete research, or are the final step in a series of fruitful research operations.

4.3 | Clusterization: An explorating context

Network clusterization suggests the innovative nature of the article studied, as its references were seldom jointly mobilized. The research theme addressed by the article studied has then become popular and the clusters have become stronger. What are the characteristics of this type?

As seen in Tables 4 and 5, the network clusterization rather concerns articles with several authors. The main authors are younger and may be women. This type is less prevalent for mathematicians and economists, and more for sociologists and biologists. They cite references with more authors and their articles are the more cited. The specificity of network-type clustering is a non-existent sociability with the cited authors, who are often unknown and rarely all known. What's about the larger intellectual context?

The network clusterization type is a smaller egocentric cocitation network but very active and involving international and interdisciplinary publications. In the details of the interviews, as in the previous category, relationships are described like chains of ties, but whose activation is due to intellectual proximity. A mathematician relates: "I met him, he was a post-doc in the United States and the person I was visiting introduced me to him; I don't know how, but in any case, there were several of us who simultaneously found that it was an interesting field to invest in." A sociologist describes her relationship as follows: "G. I think he's very close to my research center. PA, we worked together, he's the one who directed this issue of the journal. R., I know her and I really like what she does. R. and PA are friends." Another sociologist exclaims, referring to the authors of the network: "There's stuff that snakes underneath there!" A biologist clarifies that the authors in the network are not competitors but collaborators and he is even surprised not to see some links in the network that seem relevant to him.

Articles belonging to the network clusterization type are intellectually dense ones. The authors are not very connected to the authors they cite (often unknown) but identify quite well some chains of ties in the intellectual context. What are the circumstances of these publications?

Articles are often new topics for their authors. A biologist points out that the article, very central for him, is the continuation of another in which he started a theme on HIV receptors. One of his colleagues specifies that it is the first article that states her new activity on breast cancer cells when she arrived in her laboratory after a geographical mobility. One of the economists explains that the article is the beginning of a topic that will continue thereafter on Social security policy. A mathematician admits that the subject (modeling animal social behaviors) was quite new for him. And a sociologist explains that the origin of the article is linked to her discovery of a new field of research (gender studies): "I had found that they [American colleagues] had ideas that were incredibly different from ours." The engagement of the authors with the themes addressed is important, as attested by

one of the economists who exclaims "this is an article [on risk taking and pension funds] I am particularly proud of" and one of the sociologists who specifies that her article on transformation of labor market "means a lot to me."

These are new articles for their authors, a mere thematic shift or real bifurcation, but, in any case, works that really concern them, in which they are engaged. These articles are presenting like a promise for the future.

4.4 | Atomization: A rich but custom-made context

Network atomization suggests that articles mobilized an active community and then the egocentric cocitation network becomes less active and only a part of communities remains, less interconnected. What are the characteristics of this type?

As seen in Tables 4 and 5, there are more men in the network atomization and more sociologists. The number of references and their age are higher. However, the amount of citations the article receives 5 years later is quite low. Interpersonal relations associated with network atomization are characterized by a rather more discriminant sociability: they often only know some of the people cited in each reference. What about the egocentric cocitation network?

In this type, the main authors are less central and the presence of authors in the network is lower, but the size of the network is greater. It concerns more extensive networks and involves larger and more complex contexts, in terms of historicity, internationalization, and interdisciplinarity. During the interview, a biologist identifies very specific small groups related to various aspects of the issue but says, "This is very complex, I don't know what it is, I'd have to look into it." A sociologist lists all the groups he recognizes (management, sociology of finance, organization, economists...) without really knowing them: "I'm smuggling a little bit of economic sociology as an amateur without really being integrated into it." A mathematician recognizes certain groups quite well but not others: "So these are people who have worked on this kind of subject which is indirectly linked [...] from the point of view of the tools but not from the point of view of the questions we ask ourselves." An economist concludes: "So there are quite a number of groups that don't actually tell me anything." The egocentric network is described with an emphasis on groups of known authors among an unknown set.

The articles associated with the network atomization type are in a richer scientific context with a large and diverse egocentric cocitation network but the authors are not very powerful in it and the social relations between citing and cited authors are more often distant.

Authors present their articles as having connected topics or specialties in a somewhat ad hoc way for the article. A sociologist explains that the article was produced following a contract in which the funding agency (rather far away from its research topics) directly solicited them to carry out an organizational analysis on the foundation itself. A mathematician says that it was during a course that he was asked to do a "sort of overview of this set of things" (models for semiconductors). It is the same context for an economist at a "seminar in [city name] where we invited all sorts of people" to model investment behavior. A biologist specialized in protein purification (molecular biology) talks about a context of collaboration which she did not initiate: "it was X [a crystallographer] who suggested that we work with him." Another one point out the limits of his competence: "as we are not experts in microscopy, we have made a collaboration with...; as it is a system that involves original secretion mechanisms, and we are not specialists, we have called on... ."

All these elements suggest that these networks could be associated with parallel projects in which the authors of the articles studied gather recent knowledge from specialties (or subspecialties) mobilized in a particular basis. Typical articles in this category show ad hoc connections, with an implication in the present-day due to the opportunity of the article.

4.5 | Attrition: A tenuous and distant context

In the network attrition type, the existence of communities in the past suggests that the scientific community was well-structured before the publication of the studied article. In contrast, the joint mobilization of its references is rarer and more random during the contemporaneous and subsequent period of its publication. What are the characteristics of this type?

As seen in Tables 4 and 5, this type is characterized by a greater presence of female authors or mathematicians. The relationships between researchers and the authors they cite are more often characterized by close relationships: they tend to know all the authors cited in their references.

Although the egocentric cocitation network is smaller and less internationalized and interdisciplinary, the main authors are less central in the network and articles are less cited. During the interviews, the authors of the most typical articles in this category present the network with

some particular features. A sociologist says that she only knows two or three authors personally and not the others who are international references: "It is true that during my thesis, I did not make the effort to go towards international references, so these names... ." A mathematician confesses that he only knows the authors by name, except for three of them whom he has already met or with whom he has had an e-mail exchange. An economist knows the authors quite well but does not understand why they are all together because they cover different themes. And a biologist says: "I have an article in common with this man but otherwise [...] the others are all competitors."

While the references cited in the article are more often familiar, the egocentric cocitation network is more distant (including in the way of commenting on it), often presented as a small group well known in an unknown general environment.

Articles associated with the network attrition present a tenuous scientific and institutional background, an egocentric cocitation network far from the author but, on the contrary, close relations with the authors cited in the article. What are the circumstances that can lead to this type of article?

In interviews, the authors of these articles refer to "old works" as one mathematician says: "it took me back to the 90 s" when he worked on non-zero degree maps (differential geometry). It could be topics that are not very well explored, as a sociologist who "did research on [run-down co-owned property] without knowing anything about it except what I knew about housing and urban policy [her PhD]." Another sociologist said that some colleagues "asked me to rewrite [an ancient] paper in the scope of their own problematic" in order to include it in a special issue on devices. Or it could be topics a little far from the author's concerns or apart from his specialty: "it brought me back to things I had looked at after my thesis," says one of the mathematicians. Another specifies that he found partial results (elliptical geometry), "I even wondered if I should publish and then I thought why not because the methods are not so bad." One biologist said that she had to stop the collaboration because the Danish colleagues no longer had the European financial and technical resources to continue. Another one confesses that "it's an article that's a bit of a stalemate" because the protein purification procedure concerned has become obsolete.

All these elements suggest that the research problem addressed in the article under study is coming to an end, either because it has reached an impasse or because it has been successfully resolved. This type of network could be associated with work that is somewhat out of date or has lost interest at the time the article is published. A common feature of the circumstances of typical network-attrition articles is to present itself as a kind of dead end without a future.

5 | DISCUSSION

If we now discuss our results with regard to the literature on science, several points can be highlighted.

First, we managed to show that there are micro dynamics at the level of a single scientific article and we were able to make them meaningful. We present the scientific process as a social movement with micro-mobilizations (Tindall, 2004) sustained by citations and social exchanges. In this way we contribute to demonstrate that science is a social activity that is not "out of the ground." We contribute to demonstrate that scientific research is a social activity that intertwines knowledge, actors and institutions for its daily practice (Riviera, 2013). In this way, we clearly show that the social circumstances of publication are articulated with the knowledge dynamics that we have identified.

As a complement to studies that focus on the emergence of a scientific specialty (Mullins, 1972) or on the segmentation into scientific communities (Abbott, 2010), we have established that these movements can be more accurately captured according to the double dynamic: vitality (the increase in the density of links) and the substructuring of a scientific community (the tendency to produce clusters). Their association (vitality and substructuring) highlights original scientific activities, as discussed later.

Like other studies before (Crane, 1972; Michaelson, 1993), we show that social relations are involved in the circulation of knowledge within scientific communities, with our specificity of capturing them through citations. We show that interpersonal links are quite decisive at this level as well. The most distant links are more prevalent when structured subcommunities develop and the closest ties, on the contrary, are more present in situations where there are no such dynamics. We join here very classical results in network analysis (Granovetter, 1973). Weaker ties between authors (just sharing the same literature) lead to the bridging of different worlds and stronger ties coincide with a bounding of the community. Interpersonal relations are also correlated with the vitality of the community. Thus, chains of ties (interpersonal or institutional) are more present in the case of network consolidation, when density increase. On the contrary, the transience of the network coincides with ilet(s) where the small group(s) of close relations are immersed in an unknown (or unfamiliar) environment. Here again,

these results are in the same direction as those that conclude to the importance of chains of ties in fostering collective action (Tindall, 2004). This seems to be also the case for the contribution to science.

We have also argued that these intellectual relationships are not ungrounded; they are framed by the contexts in which the scientific activity is carried out. We have defined two key dimensions: the scientific complexity of publications and the power positions of authors. We have shown that these contexts are stratified in terms of social and intellectual resources. Complementing other recent work on the stratification of research (Kwiek, 2019), our study shows that, just as the scientific and institutional conditions for conducting research activity are not the same for all researchers and all research fields, neither are their intellectual conditions equivalent. Thus, in the polarization dynamic, the main author is central, more often a male, senior and the emblematic discipline is economics. In contrast, the attrition dynamic displays fewer central authors, more women and juniors and particularly few economists and biologists. So, we have shown that the professional and social situation of some authors provides more resources, which is in line with some recent results on social capital in academia (Gonzalez-Brambila, 2014). This further broadens the issues related to social inequalities among researchers by showing that intellectual exchanges are also part of the process.

Finally, let us reconsider results that show important shifts to be underlined. They refer to the distinction that can be made between the scientific dynamics of polarization and clusterization. Both are marked by vitality (the links between the cited references are reinforced), but in a different way. We have shown that the difference between the two is partly due to the resources that are mobilized for the article. The articles presented as research capitalization (polarization) accumulate the most resources (individual, institutional and social), while those that expose a research-promise (clusterization) need also social resources (coauthorship and chains of ties) but mobilize as much intellectual resources (especially at the international and multidisciplinary level). The difference between the two dynamics shows the importance that intellectual ties (unfamiliar or people on whom researchers only "keep an eye"; cf., Michaelson, 1993) can have on the development of an innovation. Here, we are echoing old results that show the extent of purely intellectual exchanges between researchers and their intertwining with social relations (Crane, 1972). Although this result should be better controlled, we have seen that these intellectually based articles are finally the most cited, as if their promises were kept.

6 | CONCLUSION

At the end of this study, we were able to establish a set of results which, of course, need to be consolidated and supplemented with further studies.

Based on a set of 102 articles from well-known journals (WoS), we have identified scientific dynamics by detecting the structural evolution of publications that share common references with each of them, what we have called egocentric cocitation networks.

Then, we have distinguished contrasting network dynamics in terms of density (vitality) and modularity (structuring). We have shown that the increase in vitality (density of the cocitation network) is correlated with power position and resources for its author (centrality in the network, seniority, citations of the article). The increase in the structuring of the community is linked to a broader and intellectually richer context (temporal, disciplinary and geographical amplitude).

The combination of these two dimensions enabled us to defined four different structural dynamics, rather exclusive: network polarization, network clusterization, network atomization, and network attrition. We have shown that these dynamics are linked to the social and institutional positions of the authors, the intellectual conditions of their articles and the circumstances of the publication. The articles that accumulate the most resources in all fields are presented as research-promises (clusterization), while those that have the least are seen as dead ends (attrition). Having only intellectual resources encourages a form of ad hoc research (atomization), whereas research-achievement requires above all social and institutional resources (polarization).

Beyond this general result, we have shown that the academic capital of authors plays a role in the dynamics of these communities: their social position and their centrality. We identified here the practice of "normal science" (Kuhn, 1970) which capitalizes on a topic with the cumulative effects (the "Matthew effects" of Merton, 1968) well known by the science analysts. But, as a kind of counterpoint or alternative practice, a "structuring science" has also been identified, whose dynamism relies more on "keep an eye on" others authors. Here, the authors' academic capital (in terms of resources and centrality) is less decisive and the chance to be engaged in such a dynamic is more inclusive. We highlight the innovative inputs of a science that is less capitalistically driven but more structurally transformative, even if it seems intellectually riskier.

Finally, this article provides an understanding of the mechanisms involved in scientific change, focusing on the conditions for the emergence of new ideas that can be expected from the publishing of an original article. Its

particularity is to focus on the egocentric networks (which is unusual in this type of study), but systematically placing it in its wider scientific and social environment. Thanks to our method, we are able to produce indicators on the destiny of scientific papers that are not limited to their reception (citations) but to the way in which the knowledge they mobilize has been, is and will be (re)mobilized by a broader scientific community. Cocitations are a dynamic—possibly prospective—tool that shows how research areas are changing (Garfield, 2001). The originality of our article is to have applied them at the level of a single article. This enables us to have a micro and individualized perspective which, like egocentric networks in general, complements the more macro work and sheds new light on the phenomenon under study. This egocentric approach also made it possible for us to learn from the interviews conducted with the principal researchers of the articles and to understand how the egocentric cocitation networks are articulated to the social conditions in which the articles are produced, especially which relational and social resources are mobilized according to which destiny.

To conduct this research, we had to gather a large volume of empirical data. In particular, we interviewed each author about all his/her references and coded them. All of this takes a lot of time and is difficult to replicate. Nevertheless, we believe that this type of study can now be continue without such heavy empirical costs. Indeed, the results obtained here provide a solid basis for associating egocentric cocitation networks with social conditions of science. Applied to larger corpus with a more computerized approach, they could be useful for studying the activity of individuals or groups of researchers, understanding the emergence of new topics or research areas, or detecting scientific dynamics that are not easily or immediately visible on a more global scale.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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