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The Narrative of a Line of Research from a Feminist Perspective: Fiber Optic Sensors and Actor–Network Theory (ANT)

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Abstract: The narrative of a line of research from a feminist perspective involves describing the situated practices that contribute to understanding inequality in the construction of the social relationships that build links between human and nonhuman materialities. This paper aims to link feminist epistemology and actor–network theory to the expert network that produces, sustains and manages the design of the chemical zone of a fiber optic sensor (FOS) and of new smart materials, tracing the path of a university research group with important scientific publications that has also developed a line of work in the field of science, technology and society (STS). We are interested in the generalized division of labor and the role of science and technology in the creation of symbols in our culture, particularly in the field of expert knowledge, where research carried out by men and women constructs trajectories of academic success that are predominantly male. The transversal incorporation of gender analysis into the production of FOSs helps reveal the processes that have, up to this point, excluded women from prominent positions in publications.

Keywords: actor–network theory; feminism; gender; technology; knowledge; sensors; fiber optics

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1. Introduction

In the mid-1980s, research by Bruno Latour, John Law and Michel Callon introduced a perspective, a sensibility and a way of doing that focuses on the principle of generalized symmetry, specifically, the heterogeneity of actors, analyzing how they relate to one another in hybrid forums. The exploration of how science and technology are performed in complex societies leads to sociotechnical disputes over how to measure the number of participants, knowing that science and technology are important elements in the socialization of human beings, enabling them to establish relationships with nonhumans (Latour 2013). Ethnographic studies conducted in laboratories for more than three decades add empirical richness and value to these proposals.

The exploration of how technologies serve the production of generic knowledge and knowledge about gender is based on the cross-fertilization between actor–network theory (ANT)[1], constructivist social studies and feminist analyses of technology (Hirschauer and Mol 1995). It involves "situated knowledge" that is grounded in some form of objectivity, in the sense indicated by Haraway, imbricated with everyday practices, biological bodies and relational materialities (Law and Mol 1993–1994); practical ontologies that explain reality through the doing of things as it relates to human doing (Haraway 1995); fieldwork that moves closer to other human and nonhuman actors to think alongside them, without adopting their positions and worldviews (Haraway 2008); and observing how the practices, discourses and artifacts used by actors define limits and boundaries between environments that they performatively contribute to creating. It is thus possible to continue fighting for a society in which no single position can legitimate the silencing of others who are not supposed to count (Stengers 2019).

To describe the production, maintenance and management of expert knowledge in current knowledge economies, it is important to investigate the practices of research groups in collectives of enunciation, in their modes of abstraction, in their disputes and in their procedures and subjects of interest (Latour 2008; Stengers 2019; Despret 2004), as well as in assemblages in the sense indicated by Stengers when, referencing *La propensión des choses*, she proposes the art of emergency, namely, the disposition that makes it possible to take advantage of the propensity of things, to 'fold' them such that they 'spontaneously' accomplish what the artist, the man of war or the politician want (Jullien 2000). Such investigation is undertaken with the understanding that what exists is hybrid, multiple, continuous, moving, fluid, variable and entwined. The association between masculinity and objectivity is constructed metaphorically, hence the importance of incorporating the epistemological aspect of feminism and examining the assemblages between scientific-technological and political-normative issues. This task entails thinking with care in scientific and intellectual environments (De La Bellacasa 2017; Stengers 2017; Singleton 2012; Suchman 2007), naming nature as a nonaligned object and the mind as not necessarily objective, controlling and dominant. Care, in this sense, entails attending to the objects of study by learning proper ways of speaking from them and with them. It also entails being responsible for the becoming of an entity that one cannot control and, as with any other entity, recognizing that its existence is sustained by other entities that generate linkages that can sustain it in its becoming.

The close relationships between modernization in Spain (Aliende Urtasun and Garrido Segovia 2010; Garrido and Aliende Urtasun 2010) and nuclear technology have been addressed (Aliende Urtasun et al. 2017). The paper responds to the simultaneous understanding of the social and natural orders—without prioritizing either—to illuminate their coproduction (Jasanoff 2004). With respect to the nuclear industry, Aliende and Garrido point out how sensors (with very different natures and functions), given their sensitivity, specificity, and ability to remain unaltered in highly radioactive environments, are a hallmark of nuclear technology and its safety. Fiber optic sensors (FOSs) can be considered fluid, variable and mutable objects that can be used to formulate questions about potential objects and their semiotics in a way that makes it possible to observe, from different places, where gender is a relationship in a bounded location where thought is produced based on what we learn and how we look at such things (Stengers 2019)[2]. This approach results in a sociology of sensors that is produced with them and is attentive to the description of how actors and organizations, mediators and intermediaries shape the situations, collectives and institutions through which the scientific-technological circulates. It considers FOSs as a provisional outcome of a heterogeneous fabric of relationships that are endlessly experimented with, tested, reorganized and capable of designing and producing what the chemist wants. If there is art, writes Stengers, it is because chemical 'actants' are defined as 'active' without their activity being able to be attributed to them; it depends on circumstances, and chemists' art creates circumstances in which they become capable of producing what the chemist wants: the art of catalysis, activation and moderation (2019).

This paper links feminist epistemology and actor–network theory to the expert network that produces, sustains and manages the design of the chemical zone of a fiber optic sensor and of new smart materials, tracing the path of a university research group with important scientific publications that have also developed a line of work in the field of science, technology and society.

FOSs are regarded as elusive objects made of mediations expressed through the narratives that connect the practical details of "doing gender" in the day-to-day life of the laboratory. We propose a sociology of the sensor, a slow science constructed from concrete and mundane sociomaterial practices. Finally, in contrast to slow science, we recognize an accelerated and competitive science that involves rapid peer review, quality indicators and publications designed for colleagues that keeps female researchers far removed from positions of power, recognition and control. The transversal incorporation of gender analysis into the production of FOSs helps highlight the processes that have, up to this point, kept women out of prominent positions in publications.

2. Materials and Methods

To trace this path, we conducted participant and nonparticipant observations at laboratories and scientific facilities along with in-depth interviews, focus groups and a virtual ethnography of the most significant platforms, agents and groups in the field of sensors, emerging technologies, expert knowledge and its public dimension (see Table 1). We are interested in exploring the generalized division of labor and the place of science and technology in the creation of symbols in our culture, particularly in the field of expert knowledge, where the research carried out by men and women constructs trajectories of academic success that are predominantly male.

Table 1. Interviews and participant and nonparticipant observations conducted during field work.

SEMISTRUCTURED PERSONAL INTERVIEWS			
Code	Gender	Age Range	Organization/Location
I1	Woman	35–45	Institut Laue-Langevin (ILL), Grenoble
I2	Man	35–45	C-Lab, Grenoble
I3	Man	60–65	Public University of Navarra (Universidad Pública de Navarra—UPNA), Pamplona
I4	Man	60–65	University of Oviedo (Universidad de Oviedo—UNIOVI)
I5	Man	65–70	Aragón Materials Science Institute (Instituto de Ciencia de Materiales de Aragón—ICMA), Zaragoza
I6	Woman	40–45	ICMA
I7	Man	55–60	UPNA, Pamplona
I8	Man	55–60	UPNA, Pamplona
I9	Woman	35–40	UPNA, Pamplona
I10	Man	30–35	UNIOVI, Oviedo

Nonparticipant Observations		
Code	Organization/Location	Date
NPO1	European Synchrotron Radiation Facility, Grenoble	April 2014
NPO2	Institute for Advanced Materials and Mathematics (Instituto de Investigación en Materiales Avanzados y Matemáticas—INAMAT), Pamplona	May 2019
NPO3	Aragón Materials Science Institute (Instituto de Ciencia de Materiales de Aragón—ICMA), Zaragoza	Zaragoza, March 2015, April 2016, May 2017, 2018
Participant Observations		
PO1	Institut Laue-Langevin (ILL) Grenoble	April 2015
PO2	Public University of Navarra (Universidad Pública de Navarra—UPNA) Dept. of Chemistry, Pamplona Laboratory	2015–2020
PO3	Institut Laue-Langevin (ILL), Grenoble	June 2016
PO4	Institut Laue-Langevin (ILL), Grenoble	June 2018

3. Results

3.1. The Connections and Links of an Elusive Object: Situated Knowledge

ANT is a set of semiotic-material tools, sensibilities and ways of working that make it possible to approach and analyze any subject. By tracing networks of relationships—both localized and in motion—a materialist narrative emerges that is meticulous and committed to becoming and change. Such accounts address each action as reality is unfolding, allowing us to be affected by the actors and observe connections, mediations, links, translations and relationships. In dialog with feminist thought[3], ANT produces a renewed vision of the world and of life and an understanding of bodies, experiences, vulnerability, subjectivities and how actors with different natures, human and nonhuman, shape one another. It reveals an agency distributed across a multitude of ties and dispersed throughout an actor–network. Grasping this agency requires curiosity and cultivating perception and deceleration to incorporate reflections on the relationships between masculinity, power and authority (Code 1991; Fox Keller 1982; Harding 2004). This process is what Haraway calls "staying with the trouble" (2016), which "requires learning to be truly present", "becoming-with each other in surprising relays" (2016) and cultivating the modes of abstraction and symbiosis required by a slow science that is interested in the inequalities produced by delegation between "actors" (Wajcman 2006), which transforms the categories of male and female and, correspondingly, those of mind and nature (Fox Keller 1995). This process involves "a 'public intelligence' [intelligence publique] of the sciences, involving the creation of intelligent relationships not just with scientific outcomes, but with scientists themselves" (Stengers 2019), seeking the simple location (Haraway 1995), i.e., specificity in the analysis of specific situations. Considering this development of a line of research focused on expert knowledge of the chemical dimension of an FOS, we ask how to contest hegemonies through feminist epistemologies that seek new, more self-conscious foundations for knowledge production (Alcoff and Potter 2013).

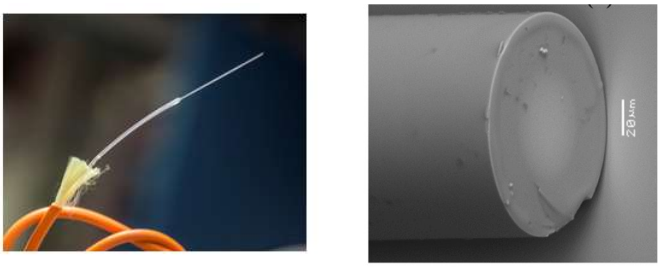
A perspective from ANT[4] and from authors such as Haraway[5] proposes the recognition of the partiality of our worldviews, the plurality of modes of existence and the locality of the knowledge produced and of the resulting ontological identities. Location involves the vulnerability, materiality and commitment that is directed at each of us, situated where we participate in the making of the world through relationships and the components that we gather when we make our scientific constructs—both those we add and those we leave out—hence, the importance of situating oneself by attending to others who ask different questions, importing them into the situation differently, relating to the situation in a way that resists appropriation by an abstract ideal (Stengers 2019).

We move between the subjects that concern us—*matters of concern*—the facts described by the sciences—*matters of fact*—and a *careful knowledge* of the situation in which we place ourselves as male and female researchers, including the relationships we have and what is involved in *thinking with care* in scientific and intellectual environments (De La Bellacasa 2017).

Sensors are gradually incorporated into the account—through a partial, contingent and precarious narrative proposal—in relation to sociomaterial practices, instruments and equipment that inform and are informed by our bodies, the structure of our laboratories, the rhythms of our work and the form of our technologies and are entwined, in tension, in a multiple reality (Haraway 2008, 2016). They are made of humans and nonhumans sharing the movement and dynamics—with their tensions, agreements, consensus and conflicts—that male and female researchers mobilize around them, becoming responsible for an entity that they cannot control. These discourses and practices deprive female researchers of the recognition and value of scientific publications.

From this perspective, sensors are relational processes—elusive objects that make it possible to dissent from within—that involve a multiplicity of mediators and intermediaries that construct formats, standards and metrologies. They comprise instruments, materials, protocols, graphs, isotherms, membranes, reagents, documents, xerogels, laboratories, universities, research institutes, publications, large facilities, companies, patents, etc. They allow the minute and invisible world to be accessible to male and female researchers. The design, production and use of structures and forms at the nanoscale involve tracking the arrangement of atoms and molecules. They produce articles that bring order to the tangle of experimental data and invent objects that are portable, legible and combinable (Law and Mol 2001).

In the 1960s, the ability to transmit information through electromagnetic waves and the use of optical fibers for transmission revolutionized the world of telecommunications. These were new material devices that emphasized connections (Latour 2008). Using sensors, we monitor the physical world, controlling different conditions at different points, continuously and in real time. Over the years, the structure, strength and flexibility of optical fibers have changed considerably, providing important sensing capabilities for capturing many parameters of environmental, industrial, medical, clinical and chemical interest. An optical fiber is a silica device (Figure 1) coated with several layers of plastic materials that allow it to be manipulated.



(**a**) (**b**)

Figure 1. (**a**) Optical fiber; (**b**) SEM micrograph of the chemical sensing zone of an FOS with reflection geometry (xerogel membrane at the tip). Taken from Echeverria et al. (2016).

The number of sensors and scientific publications about optical fibers increases daily. Describing the material basis of these devices from a feminist research perspective involves carefully examining the processes to take responsibility for the results. Only by eliminating the presence and absence of the scientist is it possible to transform the scientific object into a simple fact and obviate any time or context (Fox Keller 1991). Doing so requires a narrative that makes our experience intelligible and produces meanings about it (Morson 1988; Polkinghorne 1988) while describing the care and fragility inherent in scientific practices involved in constructing an FOS. Thus, the protocols capture all the details, and the procedure clearly standardizes the steps. Male and female researchers need to follow the indications while allowing the situation to define itself in a certain way. The heuristic potential of sensors is fertile, offering an irreverent perspective on perception, matter and reality.

Rather than focusing on transparent, neutral, descriptive language not constructed by humans, we attend to concepts formed and gendered by the logic of care and experimentation. Experimentation in this sense is the continuation of observation by other means. This approach makes it possible to move from considering FOSs as an object of study—clearly circumscribed and defined, homogeneous and static, with a prior and independent existence—to asking questions about them: what are they? Specifically, how is the chemical sensing zone of the sensor imagined, circumscribed and considered in detail? What knowledge is produced during experimental development? Are FOSs developed only to publish articles? What materiality is involved? What actors[6] are defined in these practices? Do we need new metaphors? How are these questions related to power structures that empower and strengthen women rather than undermining or devaluing them?[7] How can we make explicit how the marginal position of women in publications is constructed? How can we create accountability for results published in scientific journals when the processes deny women recognition?

This approach is in line with the work of Law and Mol. Their research shows the multiplicity of reality and the coexistence of human and nonhuman actors in hospitals and laboratories (Law and Mol 1993–1994; Mol 2002; Mol et al. 2010). We underscore their emphasis on material practices in relation to knowledge production, given the importance of this dialog in helping us understand the day-to-day life of the research teams under analysis.

3.2. The Slow Practice of Sensor Research: Events and Mediations

Stengers describes the art of chemists, which involves not so much the art of deduction as thinking in terms of practices and events and knowing how to create a place (2019) that brings together male and female researchers, pipettes, burettes, stirrers, scales, pillboxes, mortars, protocols, reagents, samples, membranes, robots, documents, graphs, isotherms, software, etc. Thus, we come to understand—over the course of the experiments—mediations, translations, sensitivities and ways in which they coproduce an "indefinite alteration of the hidden forces that enhance the shrewdness of those who explore them" (Latour 2013) while returning to the object an even more irreverent capacity for shrewdness (Cruz Contreras 2015), making it possible to think and feel differently (Despret 2004).

A Nonsystematic Genealogy: The Importance of Serendipity

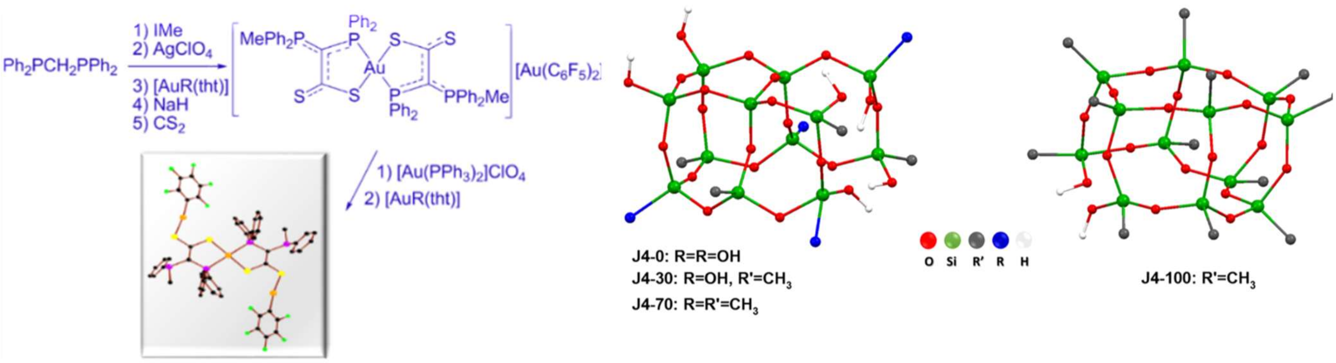
The male and female researchers interviewed recall that the line of research on FOS began in 1992, when the Inorganic Chemistry (IC) group at the Public University of Navarra (*Universidad Pública de Navarra—UPNA*) began collaborating with a related and complementary group at the Aragón Materials Science Institute (*Instituto de Ciencia de Materiales de Aragón—ICMA*), a joint institute of the Spanish National Research Council (*Consejo Superior de Investigaciones Científicas—CSIC*) and the University of Zaragoza (*Universidad de Zaragoza—UNIZAR*). At that time, the research carried out by the UPNA group focused on solid surfaces (clays, oxides, etc.) and their capacity to retain heavy metals. The UNIZAR group investigated chemical synthesis and worked on the preparation and structural characterization of new organometallic compounds at the molecular level.

The two leaders of the groups proposed an investigation of the synthesis of organometallic compounds, those with bonds between carbon and a metal—in this case, gold—to study their properties. Synthesis is the process by which two or more chemical substances react—join together—to form a more complex compound. The properties of any chemical substance are defined by its composition, structure, morphology and texture. Determining and analyzing these properties is called characterization.

Male and female researchers from both groups created strategies to achieve greater efficiency and better results, sharing resources and equipment. The first step was to produce new substances together and then to characterize them. This work is typical in inorganic chemistry. In some cases, these substances are given an application, but in most situations, the new substance is presented to the scientific community through a publication and followed, perhaps, by waiting for other research groups to consider it and assign it a specific application.

This collaboration resulted in the first joint doctoral thesis undertaken by a woman, a PhD student who carried out her work in the laboratories of the Department of Chemistry at the UPNA, where she performed the synthesis. The characterization of the materials took place in the central facilities at the UNIZAR, which had the equipment necessary to perform expensive and complex techniques. The doctoral thesis was defended in 1996 and produced seven relevant publications. The data generated by the PhD student and the positive reception of the work by the thesis evaluation committee strengthened relationships. The group leaders expressed their mutual interest in continuing to make resources profitable, undertake new projects and produce publications that would be competitive in the field. That same year, they jointly requested permission from the General Directorate of Scientific and Technical Research (*Dirección General de Investigación Científica y Técnica—DGICT*) (Ministry of Education and Culture) to conduct a coordinated project to continue the synthesis of organometallic gold compounds and analyze their properties. A new PhD student began his research with them; as in the first case, he moved back and forth between Pamplona and Zaragoza. His work in the laboratory continued to generate data and information that, together with the technical resources of the UNIZAR, allowed the nascent collaboration to flourish.

The PhD student began an experimental project similar to that described in the first student's thesis. However, when synthesizing organometallic gold (Figure 2a), he found an unexpected property. Usually, these compounds are white in color, and there is no change that is perceptible to the senses. However, this new material turned from black to orange in the presence of acetone, ether and other vapors. A physical stimulus—the presence of a vapor—produced a reversible and rapid color change. For the leaders, this change was significant enough to open up a new line of research that used the material as a sensor or as the chemical sensing zone of an FOS. Thus, through an unexpected event, the IC group began working with sensor systems, creating a new research space in a growing field where the recently initiated doctoral thesis had forged a path. All of this work was based on the hypothesis that the color change plays a key role in the sensor's measuring mechanism.



(**a**) (**b**)

Figure 2. (**a**) Molecular structure (Ino-103) (taken from Laguna et al. 1998, Patent E-9802085); (**b**) Computational chemistry modeling of the ordered domains of a hybrid silicon xerogel (taken from Ospino et al. 2017).

This circumstance produced a new actor: a gold(1)-derived ylide. This compound is colloquially called Ino-103 because it was number 103 of those obtained by Inocencio for his doctoral thesis.

The new material had little relevance in the academic and formal discourse of the male and female researchers. In moments of confidence, when they describe in detail what occurred, they stress its importance and emphasize, for example, the significance of naming the compound after the researcher. "It corresponds", they say, "with what the PhD student feels... as, in a way, he considers the compounds to be his own children". Chemical nomenclature is rigorous and systematic, the researchers insist, which is why the colloquial name Ino-103 does not appear in either the thesis or the related publications. The rigor and objectivity of science emerge as explicit arguments when the male leaders of the group relate these facts. There are no cracks in the discourse. Nevertheless, this event, seemingly minor and absent at the formal level, transformed the thesis project in terms that we would like to emphasize to understand the origins and development of the line of research under analysis. Accordingly, we identify the practices that shape and structure the professional trajectories of both the PhD student, who supplied the leaders with experimental information relevant to the group's interests and consolidation, and the other group members, who, through these findings, broadened their field of research, innovated and, most importantly, continued publishing in high-impact journals.

At the beginning, this second doctoral project was similar to the first, which was conducted jointly: the aim was to synthesize and characterize materials to publish in prestigious journals that would help the group leaders obtain funding. However, chance—serendipity—redirected the objectives from basic research to applied research and subsequently to the development of a technology: FOS. "We were lucky", they say, when they recall the origins of their work.

This circumstance made it possible to expand the collaborations to include the Department of Electrical and Electronic Engineering at the UPNA. Two national patents were obtained through these collaborations: Ino-103 (Laguna et al. 1998, Patent E-9802085) and a sensor prepared with the compound (Laguna et al. 2000, Patent E-9902862). The latter was subsequently extended to a European patent (PCT/ES00/00485). Furthermore, articles continued to be published in journals in different fields.

At this point, three research plans emerged: (a) continue with the synthesis of organometallic compounds with properties similar to Ino-103; (b) focus on the material necessary to support the organometallic compound and allow it to adhere to optical fibers; and (c) prepare and calibrate an FOS.

These three new perspectives were represented in two new doctoral theses. One female PhD student continued the synthesis of organometallic compounds with properties similar to Ino-103, while another investigated the synthesis variables of the material that supported the organometallic compound, and both students prepared an FOS. They prepared xerogels with a single silicon derivative acting as a precursor. Furthermore, the most recent papers report that the preparation of hybrid xerogels synthesized with two precursors results in the presence of alkyl and aryl groups, as well as chlorine, nitrogen or lanthanide atoms on the surface. These groups and atoms modify the surface chemistry of the gel; hence, the presence of lanthanide elements gives the material very unique properties, such as luminescence. These issues were addressed in three subsequent doctoral, undergraduate and master's theses and a number of postdoctoral contracts. The research was funded by research projects submitted to competitive calls for proposals. The leaders consolidated their position, creating appropriate conditions for the arrival of new male and female PhD students who generate data in the laboratory and continue to obtain funding to maintain and expand the equipment.

The shared laboratory work spaces enable us to identify practices based on a feminist ethos of care—care that confers on a situation the power to exist in the relationships that are constructed (Despret 2017) in the xerogel preparation practices. On a day-to-day basis, the expertise of the men and women involved in a complex data interpretation process is nurtured, which transforms the work conducted in the laboratory by male and female PhD students into a continuous movement of a network that grows by creating new material and semiotic spaces.

In the volume of work that is performed and in how these relationships are marked by gender, we can observe the difficulties of turning toward careful participatory design (Botero 2013) when the value of the research lies, fundamentally, in its publication. In turn, publications consolidate and reinforce hierarchical positions in which the beneficiaries are generally men.

The group leaders emphasize that throughout the process and until now, the primary objective of this line of research has been to explain the way in which a sensor with these characteristics measures. They argue that the objective is to explain what occurs in a membrane with a diameter of 125 microns to obtain a signal that is sensitive to the concentration of a vapor that comes into contact with it. It took several years—until 2004—for the initial hypothesis, in which the color change was considered key, to move to the second phase, which considered modifications of the membrane surface, the substance that supports the organometallic compound and attaches it to the fiber. The surface of the material used to prepare the sensing element thus began to play a key role, and the adsorption of the analyte to be detected, which takes place on the solid surface, became very important. Monitoring the development of this technology requires attention to the patterns that transform an event into action. These are not linear patterns and can be configured in different ways.

3.3. Ways of Doing: Techniques and Knowledge

The search for a material to facilitate the adhesion of Ino-103 to the optical fiber and present a refractive index—a parameter that depends on the speed of the waves in the medium in which it moves—similar to that of the fiber, leads to a discussion of the know-how involved in this work, which involves determining how reality responds to the questions we ask it with the instruments that speak the language of the theory with which they were designed (Despret 2004; Stengers 2019). The fibers used in FOSs are made of silica, and consequently, the focus was on silica xerogels and on the sol-gel process used to prepare them. During this process, there is a gradual variation in viscosity that is crucial for achieving adhesion to the fiber and to materials with individualized variations in morphology, texture and surface chemistry.

This variation in viscosity requires care at different stages of the sol–gel process. The history of hybrid materials is organized according to what are considered to be two milestones: the discovery of the sol–gel process and advances in characterization technology. The process offers great versatility in the preparation of porous materials with controlled textural and surface properties and results in a wide variety of materials that may be hydrophilic or hydrophobic and have different densities, degrees of transparency, pore sizes and surface areas. The process also opens up a broad range of applications (catalysts, nanoparticles, membranes, molecular sieves, hydrophobic, anticorrosion or antireflective coatings, thermal or acoustic insulators, nanostructured materials, encapsulation of biological materials and medicines). When the male and female researchers are asked about preparing the materials through the sol–gel process, they refer to it "as a methodology to prepare xerogels under mild conditions", meaning that the ambient temperature and atmospheric pressure are sufficient to obtain the material. However, they clarify that "to prepare materials à la carte, there must be a rigorous control of the experimental variables. It is a chemically simple procedure, not particularly complex, but it requires the utmost care and precise monitoring to obtain xerogels that are reproducible and, at the same time, different". This explanation indicates a subtle and relational perspective of know-how that demands skills and expertise.

Following the phases of the sol–gel process with the male and female PhD students responsible for making the samples makes it possible to understand the circumstances and the time required for the experimental task to be considered successful. Clearly, the simplicity of the steps involved in preparing the samples not only indicates a commitment to what is going to happen but also captures the attention and stimulates the curiosity of the male and female PhD students.

Mol's account of care in her analysis of the different hospital treatments provided for atherosclerosis (Mol 2002) can be useful for thinking about the sol–gel process. In the clinic, Mol notes that the aim is providing the best possible treatment by attuning to the elements that affect and could potentially affect the patient's life. In the anatomical laboratory—unlike in the clinic, where the patient and what happens to him or her is fundamental—the most important roles are played by microbes, tissue dissection and the body. In both cases, as in the sol–gel process, it is important to emphasize that care is a practice linked to fragility and that it is therefore impossible—as well as undesirable—to totally dominate the terrain in which it takes place. What is important is specificity: how a particular situation is defined, what elements we consider and what elements we disregard. It is a fragile practice that provides and demands care (Mol et al. 2010).

At each stage in the sol–gel process, the practice requires attention to the different variables, which can also interact between the different stages of hydrolysis and condensation, gelation, curing and drying. At a specific pH in a medium consisting of water and ethanol, the precursor, a silicon derivative, initiates a reaction whereby some molecules of the precursor bind to others, forming larger chemical species that gradually form colloids (10^{-3}–10 µm) visible through the reflection of a laser (hydrolysis and condensation stages). In turn, the colloidal particles join and generate a matrix, a three-dimensional network (gelation and curing stage). During drying, the solid acquires greater consistency and better mechanical properties. The influence of the variables makes it possible to achieve reproducible xerogels with highly individualized properties. All the steps require care and regular monitoring by male and female PhD students; additions are made with automatic burettes that continuously measure the pH and adjust it. The synthesis reagents (silicon precursor, ethanol and water) have a high degree of purity. The gelation and curing stages require controlled evaporation of the ethanol; thus, the lids of the synthesis vessels have a specific number of holes. Drying is carried out in an oven at 60 °C.

As the xerogels are synthesized, they are characterized. The thesis advisors, who also lead the research group, are responsible for coordinating access to the characterization techniques available in their central facilities with the leaders of other university institutions and research centers. The willingness of leaders and technical staff to collaborate in the required work consolidates joint strategies that are reflected in the resulting publications. There are nascent power structures that articulate shared interests in a structure that creates and maintains hierarchies. The UNIZAR and the ICMA (CSIC) are joined by the University of Jaén (*Universidad de Jaén—UJA*), the University of Oviedo (*Universidad de Oviedo—UNIOVI*), the National Carbone Institute (*Instituto de Ciencia y Tecnología del Carbon—INCAR*) (CSIC) in Oviedo and the Institut-Laue-Langevin (ILL) in Grenoble.

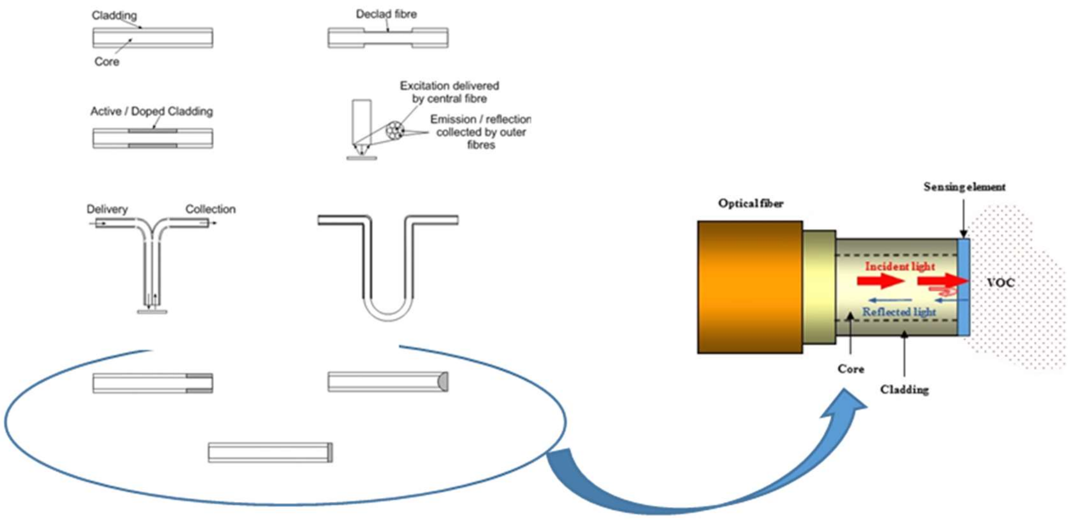
The data sent from the different institutions form a network that is being constructed through different circuits between male PhD students, female PhD students and advisors (see Table 2). Disagreements create new opportunities to think about the experimental work and demand reflection on it. Disagreements are linked to the research process as data are received. The power and hierarchy of the leaders feed the process. Electron microscopy images form the framework and the morphology. The X-ray diffraction spectrum gives an idea of the order or disorder of the silicon tetrahedra of the structure. At the molecular scale, ^{29}Si nuclear magnetic resonance determines the environment of the silicon atoms, and spectroscopic techniques—infrared and inelastic neutron spectroscopy—provide information about the bonds that constitute the structure. Thermal analysis techniques offer insight into the material's hydrophilic nature and its thermal stability. Finally, the adsorption of gases and vapors provides information on the structure's porosity. These data are crucial for envisaging a priori the xerogel's potential application as a chemical zone of an FOS.

Table 2. Places, techniques and mediations that link male and female researchers in the IC group at the UPNA to other research institutions.

Places and Techniques	Mediations
Institut Laue-Lagevin in Grenoble ■ Inelastic Neutron Spectroscopy (INS)	This technique enables measurement in all vibrational modes. It is very sensitive to vibrations involving hydrogen atoms.
UNIOVI, INCAR (CSIC) in Oviedo ■ Differential scanning calorimetry (DSC) ■ Thermogravimetric analysis (TGA) ■ Synthesis of xerogels with microwaves	These techniques make it possible to determine the heat absorbed or released during evaporation, oxidation and decomposition processes due to the mass loss produced when samples are heated at a specified temperature ramp rate (DSC) and to determine the mass loss of the samples (TGA).
ICMA (CSIC), Unizar and UJA ■ Solid-state NMR	This technique makes it possible to identify different atomic nuclei and determine the environment of silicon species in hybrid xerogels.
UNIZAR and UJA ■ X-ray diffraction	This technique enables a qualitative estimation of the crystallinity of the material and its structural order.
UNIZAR and UJA ■ Scanning electron microscopy (SEM)	Makes it possible to generate high-resolution images of the morphology and topology of solid surfaces and, in some cases, to quantify the size of pores and particle agglomerates.
UNIZAR ■ Transmission electron microscopy (TEM)	This technique enables observation of the internal structure and of particle aggregates on the order of 1 nm.

Once the physicochemical characteristics of the xerogels are known, they determine the conditions for selecting the ideal xerogel to prepare a suitable membrane for the vapor under analysis. Thus, the process of assemblage and measurement begins to determine patterns and contingencies.

Optical fibers can have different diameters and can even be made of different materials. In this case, the research focuses on 125 μm silica fibers, but there are others, the most innovative of which are photonic crystals, which allow the passage of a greater intensity of light, thus improving sensitivity. The inside comprises the core, which is the fiber itself, and the cladding, which is a coating that acts as a reflective element and ensures that a consistent beam of light circulates in the core (Figures 1 and 3).



(**a**) (**b**)

Figure 3. (**a**) Different geometries of optical fiber sensor elements; (**b**) diagram of an FOS with reflection geometry (elaborated from Estella et al. 2010).

The FOSs were prepared with different geometries to determine the one with the optimal response. Complex geometries, as shown in Figure 3a, make the measuring mechanism more difficult to explain and sometimes do not improve it. With reflection geometry, the xerogel membrane—the sensing element (see Figure 3b)—is placed at the tip of the optical fiber (OF) between two interfaces that serve as contact surfaces between two different media. The first interface separates the OF from the xerogel, and the second separates the xerogel from the medium in which the vapor to be analyzed is located. When light reaches the first interface, part of it is reflected, and part is refracted and passes through the xerogel. This process also occurs at the second interface. Finally, the light reflected by the two interfaces is measured in the detector.

To produce a sensor, the substance to be analyzed must be fixed at the second interface (adsorption), and the refractive index of the membrane must be modified to ensure that the reflected light travels a different optical path and generates a different response. The sensor's response is related to the concentration of the analyte, the amount of analyte adsorbed on the membrane and the modification of the optical path caused by the variation in the refractive index.

Furthermore, in FOSs with reflection geometry, it is possible to test different cuts in the fiber—perpendicular or bevel cuts with different angles—to increase the contact surface and the signal.

The leaders describe the "ideal sensor" in terms of its sensitivity, selectivity, stability and reversibility. Sensitivity is the ability to detect small variations in the concentration of the analyte to be detected. In the calibration curve, the sensor signal is plotted against the analyte concentration, which is how variability in the measurements of the same concentration is determined. Selectivity is the degree to which the sensor ignores interference from other chemical species present in the sample matrix. Interference is always present, and several steps must be taken to minimize their effects. Stability is related to the reproducibility and accuracy of the response in the medium and long term, and reversibility indicates the recovery time required for the sensor to return to its initial state following an analysis.

The importance of the accuracy of the measurements that generate the calibration curve is particularly noteworthy. The IC group designed and developed an apparatus capable of dosing the vapor under controlled conditions. The FOS is kept in a cell in which the analyte is dosed, and the temperature and pressure are controlled and measured (see Figure 4a,b).

(**a**)

(**b**)

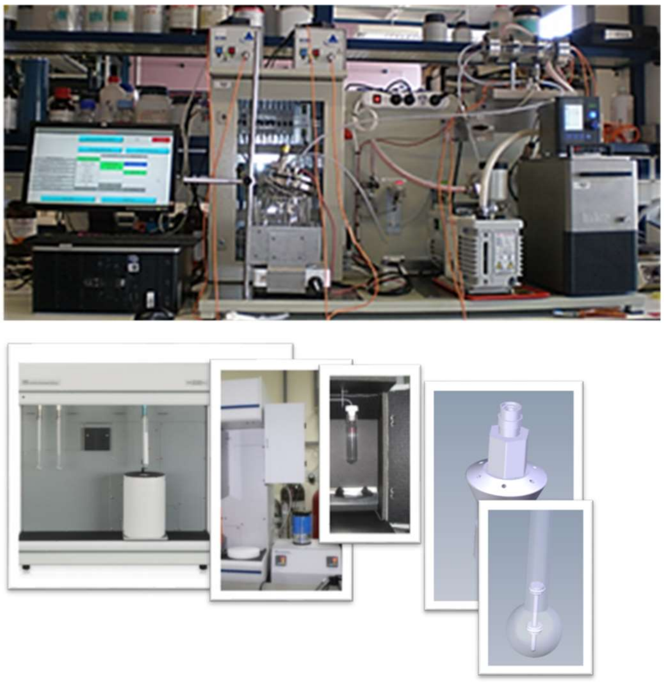


Figure 4. (**a**) A third-generation calibration system designed by the IC team at the UPNA; (**b**) a fourth-generation calibration system (adapted from a Micromeritics adsorption device for calibrating an FOS), currently in testing.

By using ANT, we emphasized the complexity of the relationships between humans and nonhumans in FOS technology. We incorporated the gender perspective as one of the most important variables for explaining the interpretative flexibility of the technology—a variable that sometimes results in unexpected production and effects—and considered that the actors occupy different power relations. In the laboratory, gender is constructed and transformed (Oudshoorn 1990). Turning our gaze toward the sensor as knowledge has led us to examine the know-how involved in this work, to the sensorial relationship that is maintained, to the hands that must learn, to the voices that must be named to operate and to uncertainty as the central axis of the sol–gel process. We articulated variables in a characterization process with different techniques that focus on the whole and its effects. Measuring and comparing can uncover correlations among numbers and can identify methods for more accurate measurement, which in turn leads to publication to obtain results and professional recognition.

4. Discussion

Accelerated Research Practice: Recognition, Value and Trajectories

Over the history of the IC group's line of research on the sensor development process, the number of female researchers has been somewhat higher than that of male researchers.

Male and female PhD students shared the same laboratory spaces, managed resources and participated in the day-to-day care required for the stages of the sol–gel process, membrane preparation and sensor calibration. Nevertheless, significant gender inequalities were created during the scientific production process.

It is common knowledge that although there are differences among scientific fields and areas, women publish fewer articles than men, on average. Women are also less likely to participate in collaborations that lead to publication. We are particularly interested in assessing the byline order of male and female authors in publications, which provides an opportunity to reflect on the growth of collaborative research and other changes in academic practices that contribute to creating conditions of greater equity.

In this section, we present the relationship between gender and research outcome, analyzing the 36 publications produced in this line of study. We consider the authorship of the articles and the degree of collaboration through coauthorship. We also examine the scientific impact of the articles published between 1996 and 2020, as indexed in the Thomson Reuters Web of Science (WOS). Figure 5 shows the total citations of the 36 published articles (732 citations), indicating the individual citations.

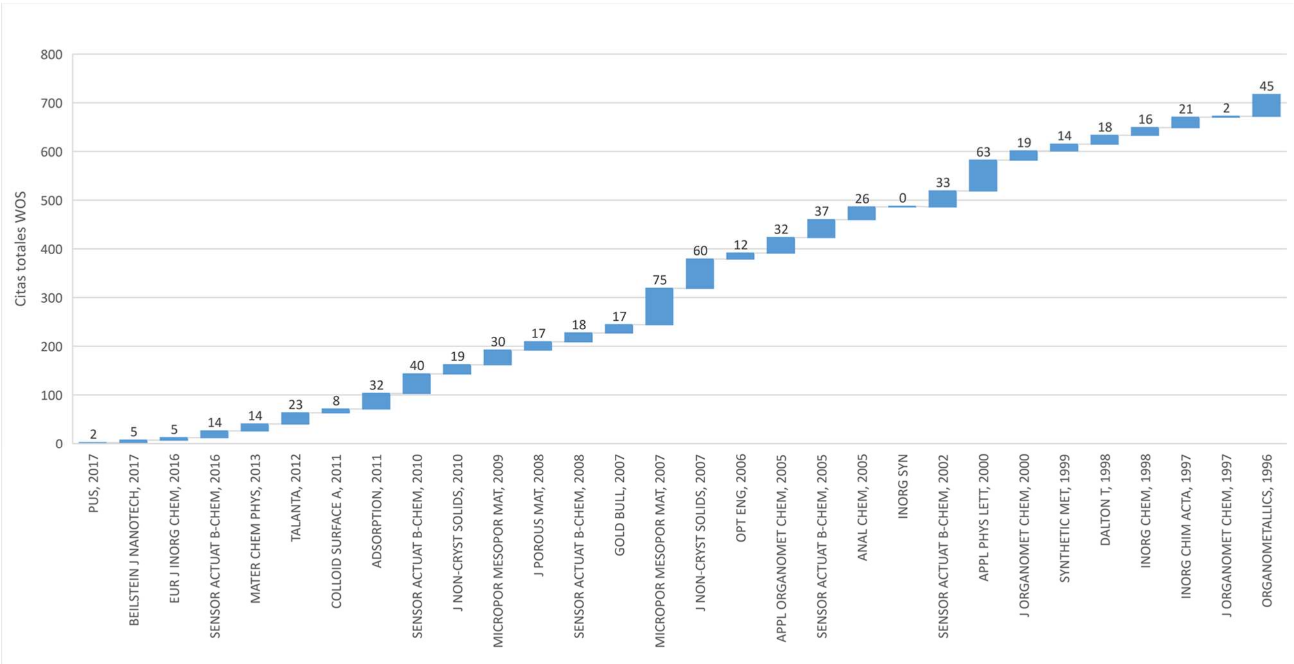


Figure 5. Cumulative frequency of total citations of each of the 36 publications from the line of research on sensors in the IC Group (UPNA). Data taken from the WOS (2 October 2021).

The publications produced by the research group demonstrate the consolidation of scientific careers. The recognition and value of the work performed generates successful trajectories primarily for men. The professional trajectories reveal the mechanisms of a process involving the disappearance of women scientists and technologists from positions requiring academic recognition through publications and their re-emergence in other areas, where they are recognized as having greater epistemic authority (Berryman 1983; Clark Blickenstaff 2005).

From 1996 to 2020, a total of 36 papers with 194 bylines were published in this line of research (Figure 5). The number of bylines differs from the number of authors, as several male and female authors contributed to more than one paper. Of the bylines, 132 correspond to men (68.0%), and 62 correspond to women (31.9%); see Table 2. The calculation of the number of bylines per author also reflects this difference (31 male authors versus 23 female authors). Consequently, the average number of bylines by female authors is also lower.

One indicator used to measure collaboration among researchers is co-authorship. Of the 36 papers, the collaboration rate for men is 3.7 bylines/paper; for women, it is 1.7 bylines/paper (Table 3).

Table 3. Productivity of the authors and collaborators (coauthors). Data separated by gender.

	Bylines	Authors	Papers	Average Bylines/Author	Average Bylines/Paper
Male	132	31	36	4.3	3.7
Female	62	23	36	2.7	1.7
Total	194	54	36	3.6	5.4

There are scientific fields and research groups in which author bylines are presented in alphabetical order. In most cases (93%), the byline order is significant in terms of the author's contribution to the work (Sauermann and Haeussler 2017). Authorship is an important issue, as publications play an important role in the recognition of a researcher's professional trajectory at universities and research institutions. Byline order can be used to infer the contributions by male and female researchers and varies according to research field.

In the line of research examined in this paper, six doctoral theses have been defended (a seventh will be presented next year); of these, four are by women, and two are by men. This distribution is mirrored in the analysis of the byline order in the 36 articles (see Figure 6), 21 of which have a woman as the first author. The last authors are the directors of the research, known as corresponding authors, who send the article to the editor and handle all the correspondence; their e-mail address also usually appears on the first page of the article, allowing them to serve as the contact person for other researchers. In 59% of cases, the corresponding author is the last author, and in 32% of cases, it is the first author (Larivière et al. 2013).

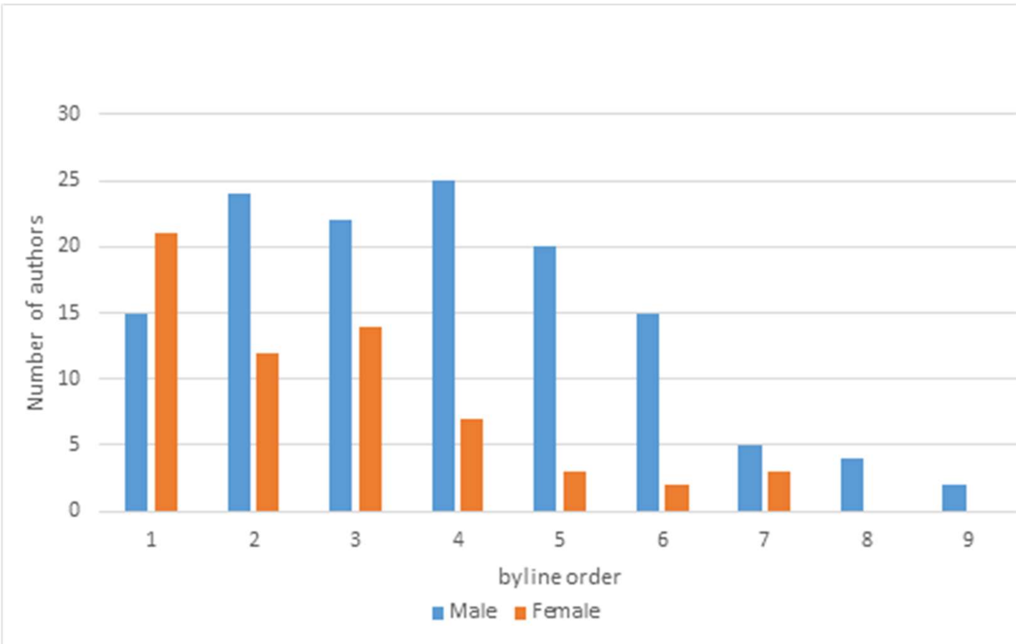


Figure 6. Number of male and female authors by byline order.

Starting with the second byline, men author more papers than women. These authors are collaborators from other institutions who made specific contributions that enriched the paper, such as conceiving the study, conducting the literature review, supervising the project, designing the experiments, conducting the experiments, analyzing the data, running computer simulations, extracting the results and conclusions, writing the article, translating the article, preparing the figures, etc. This process entails an unequal division of labor among the different coauthors.

The ratio between each position in the byline order and the mean value for each gender provides a parameter (gender concentration of bylines in each position). This parameter is shown in Figure 7. This figure clearly indicates that the highest concentration of females is as first authors. The work carried out in the laboratory and the importance of the results describe the beginning of a trajectory in which women position themselves and contribute to scientific production.

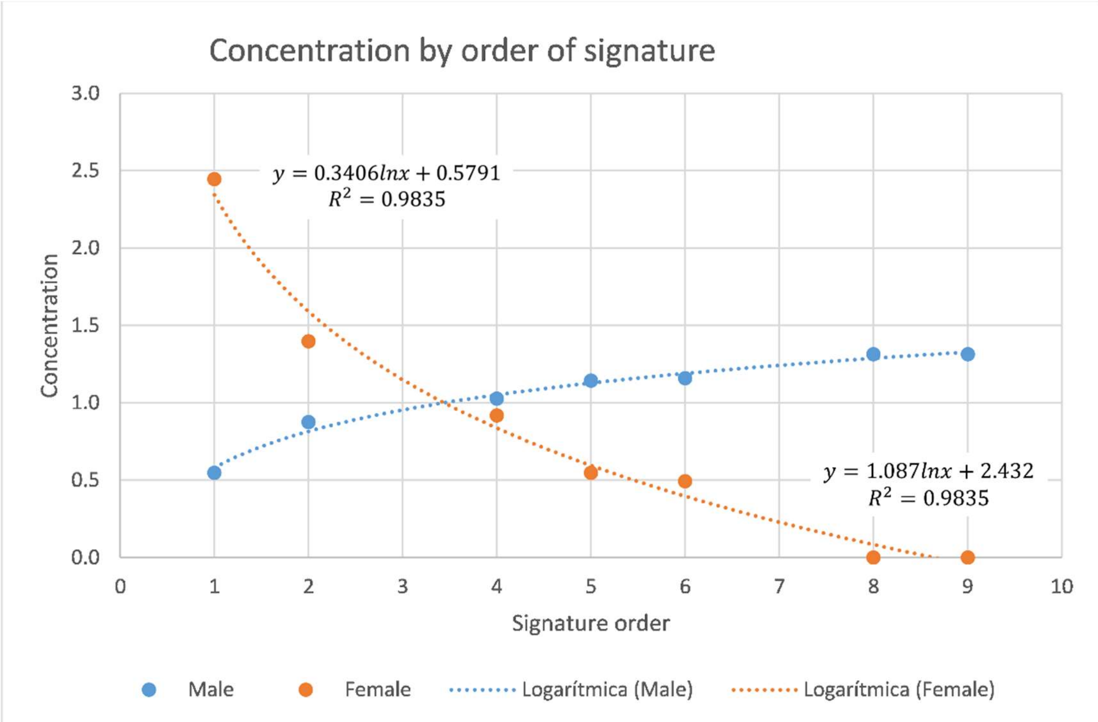


Figure 7. Concentration of men and women according to their position in the byline order.

These trajectories, however, suffer from leaks that occur throughout women's lives, in many cases causing them to leave the world of science. This reality is described using the metaphor of a leaking pipeline (Clark Blickenstaff 2005). The validity of this metaphor in the research group under analysis indicates the lack of a female presence in the advanced stage of a scientific career, specifically in terms of publication mechanisms that create unequal opportunities for men and women.

5. Conclusions

The narrative of a line of research from a feminist perspective involves describing the situated practices that contribute to understanding the inequality in the construction of the social relationships that build links between human and nonhuman materialities. In the process, we found that even when participants do not act in a traditional or patriarchal way in laboratory practices, androcentric values that have prevailed throughout the history of science are present. This fact implies a hostility toward the conscious articulation of a feminist scientific position when the topic of FOSs is considered from a sociological perspective.

The construction of an FOS involves three types of knowledge: first, knowledge about the different techniques for knowledge construction; second, knowledge about the materialities that make this construction possible, including siliceous precursors, ethanol, fibers, membranes, calibration equipment, etc.; and third, knowledge about the bodies associated with the practices and the effects of their execution in laboratories, in other words, creating professionals and "doing gender". The results of that knowledge, as presented in the publications produced by the research group, reflect gender asymmetries in the professional trajectories of men and women and clarify the importance of creating—collectively—new possibilities for thinking with care about experimental work, its logics and its outcomes.

We examined inequalities using qualitative research methods that capture the plurality of experiences of male and female researchers. The interview scripts and questionnaires were designed to clarify relevant gender differences in the data. We collected and examined disaggregated results to identify and understand gender differences in knowledge production and innovation. The transversal incorporation of gender analysis into the production of FOSs enabled us to understand the processes that have, up to this point, kept women out of prominent positions in publications.

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Notes

1 The use of the acronym "ANT" for "actor-network theory" is a play on words: the work of ants and their tunnels metaphorically illustrate the approach to research in ANT.

2 The introduction of a new line of research in the field of STS by the Inorganic Chemistry group at the Public University of Navarra (*Universidad Pública de Navarra—UPNA*) was born of curiosity and of "becoming capable of learning again, becoming acquainted with things again, reweaving the bounds of interdependency. It means thinking and imagining, and, in the process, creating relationships with others that are not those of capture" (Stengers 2019). We are particularly interested in the mediation and effects of science and technology on our ways of life and in the processes involved in their production.

3 In her text *The Science Question in Feminism*, Harding analyzes different feminist positions that are critical of science, along with their epistemological approaches and their consequences for the consideration of science. On the subject of gender, the author differentiates three levels. At the first level, she refers to the dualistic gender metaphors that mutually validate and support one another: nature-culture, subject-object, etc. These metaphors represent gender symbolism (or totemism): an ideology that structures the policies and practices of science institutions. At the second level, the level of gender structure, the relationships between men and women in the context of scientific activity are portrayed. At the final level is individual gender, a form of identity that is often imperfectly configured (1996).

4 Latour quotes Deleuze, suggesting that the proposal be called "actant-rhizome theory", emphasizing the precarity of processes and connections (Latour 1999).

5 For Haraway, this recognition implies learning to be present "as mortal critters entwined in myriad unfinished configurations of places, times, matters, meanings" (Haraway 2016).

6 Departing from anthropocentric approaches, "actors not only act, but they are habilitated and produced as such as a result of complex relations with other actors. That is, to become actors, they have to be enacted" (Law and Mol 2001).

7 We know that there is no nature free of political and social elements (Harding 2004). The ability to imagine a political order depends on a certain definition of science. However, science and technology can no longer provide the kind of domain from which a calm and sane political reason can emerge (Latour 2004).

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