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Models of Teaching Science Communication

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Abstract: Changes in the communication ecosystem have generated profound transformations in current science communication. In the same way, the coexistence of diverse actors with different objectives and professional standards also raises new ethical dilemmas. The main objective of this research was to identify existing models of teaching science communication to scientists and professional communicators worldwide. To this end, we conducted 26 semi-structured interviews with science communication teachers from 15 different countries. From these interviews, we identified three models of teaching science communication to scientists: (A) the practical model, where skills such as writing, public speaking, etc., are taught; (B) the reflective model that teaches theory and the history of science communication to enable researchers to understand the relationship between science and society; and (C) the disruptive model, where traditional roles of scientific knowledge production as well as relationships and power roles in science are challenged. On the other hand, we have identified two models for professional science communicators: (A) the professional model, which is subdivided into two different approaches—theoretical (historical review, understanding of the science–society relationships, etc.) and skill-based (writing, audiovisual, etc.) that coexist in teaching programs—and (B) the research model, where tools, concepts, and methodologies for science communication research are taught.

Keywords: science communication; phenomenological interviews; public scholarship; science for non-scientists; science in media; science education

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1. Introduction

Science communication as an object of training and research is relatively young [1,2]. In recent decades, however, a genuine effort has been made to reach a consensus on the professional, "disciplinary", and thematic bases that constitute the cornerstones of the field, and to find empirical evidence and theoretical frameworks to advance it [3–6]. Although science communication, or the public communication of science and technology, is now accepted as an academic field in its own right, there are still debates around it [7].

According to the Analytical Framework of Science Communication Models, public communication of science tends to adopt different approaches that can be grouped into three models: the dissemination model, the dialogue model, and the conversation model [3]. Today, we could probably replace the term *conversation* with the broader term *participation*, thereby including the notion of cross-talk [8], a range of activities that promote greater citizen engagement with science (including do-it-yourself, Fab Labs and Social Labs, the maker movement, and citizen science), and new approaches to science itself (including community-based research, engaged research, science shops, and patient and public involvement).

On the other hand, changes in the communication ecosystem have generated profound transformations in current science communication: in the channels and formats used—languages, products, media, etc.—as well as in the actors that participate in the communication and their interactions [9]. These transformations raise new questions about, for example, the nature of today's science communication and its functions, or how to identify a best practice. Similarly, the coexistence of different actors with different objectives and professional standards also raises new ethical dilemmas. Jean Goodwin suggests that, in order to understand the ethical issues that emerge from this new panorama, it is useful to think that science communication takes place through speech acts, emphasizing the communicator's ethical responsibilities towards an active audience and concluding that science communication is only effective when it is ethical [10].

It is important that communication professionals involved in public information on scientific, medical, and environmental issues produce high-quality work, and therefore that they receive adequate training to enable them to do so [11–15].

Science communication training is emerging as an object of study and research. Scant literature on the training of future science communicators—scientific journalists, institutional communicators at universities and research centers, and professional communicators at science museums and outreach centers—as well as, to a lesser extent, the training of scientists and future scientists in communication, is readily available.

1.1. Theoretical Framework

1.1.1. Science Communication as a Part of a Scientist's Job

Every year, numerous scientists are consulted worldwide as information sources, or participate in communication actions for the general public. Scientists (researchers, medical doctors, and professionals from other scientific disciplines) are more present every day in public communication, whether giving their opinions in their capacity as experts, or acting directly as communicators. In this regard, we must bear in mind that professionals in scientific disciplines communicate not only with the media, but also directly with the public or specific groups.

Despite outreach activities being organized and managed by communication professionals, the participation of researchers is also expected [16]. The involvement of scientists in public engagement activities is highly valued by the public because they speak with in-depth knowledge of the topic, and from a first-person perspective [17]. A number of studies suggest that some scientists strongly believe they should play a role in public debates, with policymakers in particular [18]. Science communication is also seen as a shared responsibility between scientists, journalists, and science communicators working at universities and research centers [19].

In this context, it is paradoxical that most scientists have never been trained in science communication [20,21]. Therefore, their innate capacity for communication or their years of experience will be the only determinants. In the last decade, the shortcomings of this issue have been highlighted, and also the need to promote communication training among scientists [13–29].

The facilitation of training that helps scientists become better communicators and that provides them with tools to anticipate and overcome the barriers and problems currently holding back science communication could lead to more widespread, better-quality science communication.

According to Baram-Tsabari and Lewenstein [25], different courses can be tailored to different goals (e.g., for scientists who wish to remain in science, become journalists, or work for museums), while conceptual coherence can help course designers identify important goals. In 2009, the European Science Communication Workshops (ESCW) brought together many of the leading science communication trainers in Europe, collated and updated the resources of the European Network of Science Communication Teachers (ENSCOT)—its predecessor network, and expanded its experience in training communication scientists [26]. In a recent study in which trainers from North America were interviewed, of the four selected communication objectives (increasing knowledge, fostering excitement, building trust, and framing issues), only the first of these (increasing knowledge) was clearly and regularly referred to by the trainers without prompting [27].

1.1.2. Science Communication as a Profession

The current existence of numerous science communication training programs around the world provides a valuable resource from which to identify the contents, competencies, and learning outcomes that are—or should be—included in such educational programs, as well as their adjustment, or lack of it, to the real-life needs of professional practice. We have ample evidence of science communication teaching programs in the 39 countries represented in Communicating Science: A Global Perspective [30]. There are university courses in science communication running in 35 countries. The pioneers were the Philippines and the United States in 1960, the average courses started in the 2000s, and Ghana (2019) is the most recent country to offer courses.

John Turney (1994) [11] identified three types of science communication training: (1) training in skills for working with and in the media; (2) mixed training, combining skills and theory; and (3) complex training, which combines learning skills with specific scientific disciplinary content.

In 2003, the European Network of Science Communication Teachers (ENSCOT) gathered data on training programs taught by its members in different countries across Europe. The first series of recommendations and training modules [31] was the result.

From these early investigations and efforts to achieve collective knowledge on science communication training, a number of works about teaching programs around the world have been published [7,18–25,32–39]. Yet, many other teaching programs have yet to be documented in the scientific literature. We know of their existence because of their presence at the major international and national conferences in the field, and by their network presence. As stated in the book Communicating Science: A Global Perspective, some of the existing science communication teaching programs date back more than 60 years [30].

Based on the results of two seminars held during the 10th International Conference of the Public Communication of Science and Technology (PCST) network, Mulder et al. [23] published their analysis "The State of Science Communication Programs at Universities Around the World" and proposed a model of four areas of knowledge (science, educational studies, social studies of science, and communication studies) under which science communication training would be framed. Additionally, based on the opinions of specialists in science communication, but this time from a study based on the Delphi Method, Bray et al. [40] identified 10 essential statements in a science communication course. More recently, Rodgers et al. [28] have proposed a scale to measure the effectiveness of science communication training that may help to identify which aspects of the program are working well and which need improving.

There is currently a lack of consistent evaluation criteria for systematic assessments of science communication activities [29]. This means that, in many cases, it is impossible to know whether or not the participation has been successful, and its objectives achieved [41]. The inclusion of this corpus of knowledge in the training of professional communicators is therefore essential.

One problem cited by directors and promoters of science communication teaching programs [36] is that some programs are particularly exposed to the escalating rationalization of higher education institutions in many countries. In an essay in *Nature*, Boyce Rensberger explains that the role of science journalists has gone from the primitive role of "cheerleader" to that of "watchdog" [42]. However, there is very little literature with which to investigate this claim, and even less to conclude that students of science journalism are learning the primary functions of their profession.

1.1.3. Training Other Actors in Science Communication

During the last twenty years, numerous attempts to stimulate participation in science have emerged. A general trend towards broader stakeholder engagement in science and technology projects can be seen in a wide range of research and coordination activities [43].

Worldwide, millions of citizens are engaging in thousands of research projects in collecting, categorizing, transcribing, and analyzing scientific data even in identifying research questions or in other previous research phases. These projects, broadly labelled as "citizen science", are heterogeneous and cover a wide variety of topics [44]. Many terms and expressions are used to refer to this concept and its practitioners [45,46], but the most widespread definition of citizen science is that found in the Oxford English Dictionary: "the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists" [47].

Many different societal actors, such as researchers, public administrations, policymakers, industry, and civil society, are involved in citizen science projects. In this situation, communication becomes a key tool: to engage volunteers and maintain the relationship between citizens and the research team, for example. In addition, citizen science projects usually incorporate an initial phase of training participants which means that project managers must have a good grasp of key concepts of communication and evaluation of learning outcomes [48,49].

A multidisciplinary team is an essential requirement of a successful citizen science project. It is crucial that researchers receive training that enables them to explain the importance of the project, develop clear and comprehensive project support materials, and ensure appropriate participant feedback, among other things [50]. Training of the different actors involved in this type of project has yet to be explored, however.

As we have seen, it is necessary to further explore different approaches to teaching science communication. In the present study, we address this issue by interviewing science communication teachers to identify different approaches to the teaching of science communication to different publics and provide answers to the following research questions:

- RQ1. What are the different models of teaching science communication to scientists?
- RQ2. What are the different models of teaching science communication to communication professionals?

2. Materials and Methods

We conducted 26 semi-structured interviews with science communication teachers from 15 different countries to answer these questions. We used a qualitative approach, as our intention was to explore the personal perceptions of interviewees and their arguments regarding different ways of teaching of science communication to different publics (scientists and future science communication professionals).

2.1. Semi-Structured Interview Script

In this section, we present the questions of the semi-structured interviews:

(a) Starting questions:
  - Name
  - Age
  - Institution
  - Years working on science communication
  - Years teaching science communication
  - Teaching level: undergraduates, masters' programs, PhD courses?
  - Target audience: scientists, communicators/journalists, future science communicators?

(b) Study dimension—teaching science communication to different actors:
  - Do you think that there are different approaches to teaching science communication to scientists?
    - What are these approaches?
  - Are there different approaches to teaching science communication to students that want to become science communication professionals?
    - What are these approaches?
  - Can you identify any inspiring teaching practices?

- Do you think that, for science students, science communication is considered as a career option such as research, teaching, or business etc.?

Figure 1 Diagram of the methodological process shows an overview of the research method used for this study:

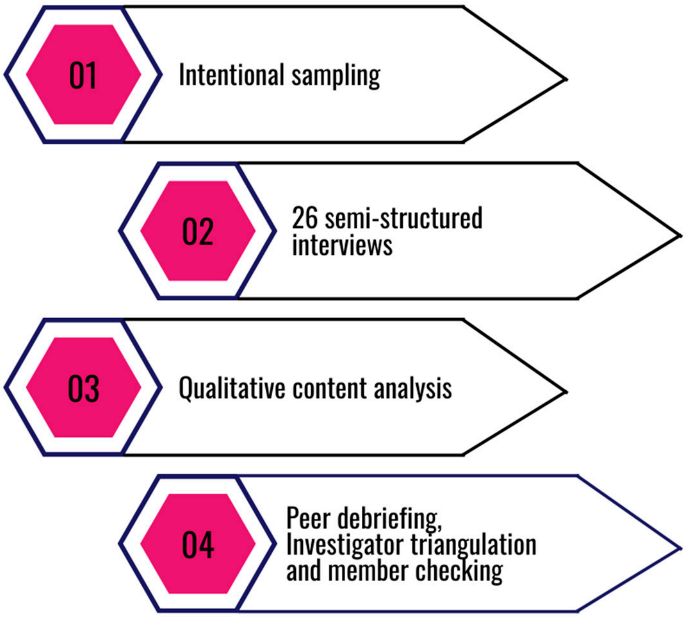

Figure 1. Diagram of the methodological process.

2.2. Sampling

Intentional sampling was used to select the interviewees. From the existing literature and the participation in the main conferences of the sector, we identified 58 science communication teachers who directed or coordinated master's degree programs, science communication workshops, or specific science communication courses included in other degrees, whether communication (e.g., journalism or social communication) or science-related (e.g., biology or chemistry), and who had made meaningful research contributions to this field. According to Helmer et al. [51], we considered "meaningful" research that has value in itself by being intellectually stimulating, and/or that has a positive impact on society in the form of practically useful research.

The science communication teachers selected were sent an e-mail describing the project and inviting them to participate in an online interview. Up to three follow-up e-mails were sent to solicit participation from those who initially failed to respond. An additional effort was made to guarantee at least 40% of the less represented gender in the sample. Eventually, contact was made with 41 teachers, of whom 32 responded and 6 declined to be part of the study due to lack of time. Interviews were therefore completed with 26 people.

The interviewees comprised 15 males and 11 females, with an average age of 51 (SD = 13). All the interviewees had completed higher education, and most of them had been involved in science communication teaching for more than 20 years (n = 9). The exact composition of the sample is summarized in Table 1.

Table 1. Interviewees' involvement in science communication and teaching.

Number of Years Teaching Science Communication	N	% Sample
10 or under	8	31%
11 to 20	9	35%
21 to 30	7	27%
31 or more	2	8%
Number of years working in science communication	**N**	**% sample**
10 or under	6	23%
11 to 20	8	31%
21 to 30	9	35%
31 or more	3	12%

The composition of the sample was designed to represent teachers of different levels of studies (e.g., undergraduate, master's, or Ph.D. workshops) and different student profiles (see Table 2).

Table 2. Description of interviewees' teaching.

Level of Teaching	N
Undergraduate	12
Master's	22
PhD workshops	6
Other workshops	7
Background of the students	**N**
Communication studies	3
Science studies	10
Mixture of backgrounds	22
Country in which the program is offered	**N**
Australia	2
Brasil	1
Germany	1
Ireland	2
Italy	2
Malta	1
Netherlands	1
Portugal	4
Russia	2
South Africa	1
Spain	2
United Kingdom	4
United States of America	1

Only one of the interviewees taught on an undergraduate program devoted to the education of science communication professionals, while three taught science communication subjects in communication studies (e.g., journalism or social communication), and the majority (N = 8) taught similar subjects as part of science and technology degrees (e.g., biology, physics, chemistry, or engineering). As we can see from Table 2, the most common scenario was teaching science communication in master's degree studies, and with mixed students (coming from different backgrounds) who wanted to become science communication professionals. Most of the interviewees taught science communication on more than one course (e.g., on a master's as well as an undergraduate program, or on a master's program as well as in PhD workshops), and to more than one audience (N = 22).

All interviewees freely gave their consent when informed of the characteristics of the study and data processing policies. All were given the opportunity to answer each one of the questions as well as to stop participating at any time.

2.3. Data Collection and Processing

We developed a semi-structured interview protocol with two interviewers (the first author and a research team member) who conducted the interviews via Skype. The interview questions can be found in the supplemental material. The first interviewer conducted 14 interviews, while the second conducted 12. The first pilot interview was conducted to validate the script. All interviews were conducted in the period from October to December of 2019. The average interview took 41 min to complete, with the range spanning from 24 to 80 min.

2.4. Data Analysis and Interpretation

A sequential analysis of the interviews was carried out and observational notes were included in the transcription of the interviews. A qualitative content analysis was used to analyze the data and interpret its meaning with the support of the research software *Atlas.ti* (version 8.4). This research method represents an objective and systematic means of quantifying and describing phenomena [52]. To achieve this, we create categories to reduce data to concepts that describe research phenomena, that is, groups of content that share a commonality [53]. However, a single quote may be highly relevant in terms of meaning.

Peer debriefing, investigator triangulation, and member checking were the strategies used to help improve the accuracy, credibility, validity, and reliability of the method. Two interviewers (the first author and a master's student) worked to analyze and code the interview transcripts, first jointly coding a sample of interviews as a means of calibration, and then working independently, achieving a high degree of reliability. Discrepancies were discussed and resolved between coders and the last author. Peer debriefing was used to ensure the collection of valid information.

The first author performed the first round of the analysis of the code compilation, while the last author reviewed the analysis and added their interpretations. The resulting joint categorization was shared in an internal seminar with the research team (both authors and other researchers and PhD students of the department), whose input and feedback was also incorporated.

Member checking, or participant validation, is a technique for exploring the credibility of results [54]. In this regard, once the study was complete, we organized an online workshop with the 26 interviewees to share all the preliminary findings. This allowed the participants to critically analyze and comment on the findings. The participants affirmed that the summaries reflected their views, feelings, and experiences, meaning that the study is said to have credibility. These member checks are not without their faults, but they serve to decrease the incidence of incorrect data and incorrect data interpretation [55]. The overall goal of the member-checking process is to provide findings that are authentic, original, and reliable [54,55].

3. Results

3.1. Teaching Science Communication to Scientists

From the interviews, we were able to identify three different models of teaching science communication to scientists, which we called practical, reflective, and disruptive models. Table 3 summarizes the different models, findings, and frequencies of this dimension of study from all the interviews.

3.1.1. Practical Model

During the interviews, the practical model for teaching science communication to scientists was the most mentioned (N = 20). In this category, we included all the interviewees' references to training models or personal educational experiences focused on providing scientists with tools and skills to perform specific science communication practices. Table 4 summarizes the main findings included in this model:

Table 3. Models of teaching science communication to scientists identified.

Identified Model	Findings	Frequency
Practical model	Refers to educational models focused on learning tools and skills to perform specific science communication activities (e.g., writing, public speaking, etc.).	20/26
Reflective model	Refers to an educational model that helps researchers understand the importance of science communication, how it works (journalistic schedules vs. research schedules, etc.), and how to interact with professional science communicators.	14/26
Disruptive model	Refers to an educational model in which structural changes are proposed within the traditional roles of researchers, the other groups of actors with whom they interact, and the production of scientific knowledge (concepts related to public engagement, open science, citizen science, etc.).	5/26

Some interviewees directly referred to "*practice-oriented*" (e.g., Interviews 1, 16), "*practical focus*" (e.g., Interview 4), or "*interactive*" (e.g., Interview 20) training programs specifically for one-day or half-day workshops for researchers (e.g., Interviews 8, 11, 23) or PhD students (e.g., Interviews 3, 10, 11, 26), as well as workshops or complete subjects (e.g., Interviews 9, 13, 18, 24, 25) for undergraduate science students.

It may seem that there is a great deal of diversity between these courses, but the main commonality of all these programs is that they are aimed at people with a science background, whether undergraduates, early-stage researchers, or senior researchers, and they all employ a practical approach. This practical teaching approach is designed to fill scientists' "*skill gaps*" (e.g., Interview 8) and create "*practical experiences close to the real world*" (e.g., Interviews 3, 4, 7, 11, 20) or "*learning by doing*" (e.g., Interview 15), such as how to behave with journalists during a media interview (e.g., Interviews 3, 12).

Some teachers mentioned specific topics they teach their students during the interviews; for example, "*writing skills*" (e.g., Interviews 8, 11, 24), "*public speaking*" (e.g., Interviews 6, 14, 24), or "*social media skills*" (e.g., Interviews 3, 11). However, we have unified all these mentions into a single group because the global meaning lies in practical teaching to solve communication problems in the routine work of researchers.

It is particularly interesting that one of the interviewees talked about teaching "*scientific writing*" (e.g., Interview 14) as a kind of first step to engage researchers in science communication training.

Indeed, one of the interviewees specifically mentioned that scientists "*wanted to talk about the story directly with the journalists*" (e.g., Interview 3) as an example of an added value of this kind of practical training. There were also mentions of involving "*journalists*" (e.g., Interview 3) or "*professional actors*" (e.g., Interview 14) in their teaching, to recreate scenarios in which students could put their communication skills into practice.

During the interviews, a number of demands or reflections on this model were raised. For example, some interviewees believed that practical science communication teaching should be a "*compulsory subject*" (e.g., Interview 9) or at least "*be present*" (e.g., Interview 24) in both undergraduate and postgraduate science studies.

Table 4. Summary of the main findings included in the practical model.

Main Finding	Literal Text Examples from Interviews
Teaching science communication to scientists is mainly practicaly-oriented.	*Our workshop is very practically focused; participants just focus on communication skills.* (Interview 4)
The teaching course is mainly designed to fill scientists' skills gaps.	*It's almost about familiarizing scientists with the media and how the media works. It's about breaking down your science into edible, digestible "tapas" rather than big meals.* (Interview 22)
The main goal of the teaching model is to solve communication problems in the routine work of researchers.	*It's almost about familiarizing scientists with the media and how the media works. It's about breaking down your science into edible, digestible "tapas" rather than big meals.* (Interview 22)
Scientific writing courses may be used as a first step to engage researchers in science communication.	*Because scientists are very aware that they need to publish papers, we would incorporate the science communication into the scientific writing process, so we would do a whole week and then we would have them start writing papers, and then we went from writing papers to making a presentation where they were talking to an audience of non-scientists, and then how to talk to journalists.* (Interview 14)
Involving science communication professionals is seen as an added value for courses to scientists.	*Our workshops have become smaller, and we've involved more journalists because the scientists want practical experiences, as close as possible to the real world that they can get.* (Interview 3)
Science communication training must be seen as part of global researchers' training.	*Science degrees should have communication subjects, whether optional or not, but these subjects should at least be present. And this is an issue that is still pending in most science faculties.* (Interview 24)

Other comments were related to the lack of reflection on the objectives of practical science communication workshops (e.g., Interview 18):

> *I think a lot of people who teach science communication have not thought very deeply about why they are teaching what they are teaching, they just teach how to write, how to produce visuals, or they really believe in this "improv" tool, and they rarely step back and say, what are my objectives, what kinds of skills am I trying to teach?* (Interview 18)

According to our interviewees, the practical model is effective for teaching specific communication skills, especially on short courses such as workshops, where one or two learning objectives can be addressed. This kind of learning is useful for completing the training of scientists in science communication, specifically to improve specific skills (such as writing, speaking in public, or interacting with journalists during an interview). It is the kind of training offered in research institutions for continuous development learning workshops, but it can also be beneficial for Ph.D. students to complete their range of skills as a researcher.

3.1.2. Reflective Model

All the teaching experiences and references (N = 14) included in the reflective model category employ a more theoretical approach designed to provide some background on science communication and to encourage reflection and increase understanding of the relationship between science communication and society (see Table 5).

Table 5. Summary of the main findings included in the reflective model.

Main Finding	Literal Text Examples from Interviews
A theoretical approach is given to make scientists reflect on the relationships between science and society.	*"We use some hours to teach theory, history and contextual issues to make scientists understand the importance of science communication"* (Interview 2)
Training scientists on the potential benefits of science communication.	*We want to raise awareness and knowledge of the different forms of science communication and the opportunities that different types of science communication can provide, like participatory science communication, like creating dialogues, and they need to be aware of the tools they can use to create that and the benefits of creating that sort of communication.* (Interview 9)
Reflections on the purpose of science communication (objectives, strategies, evaluation) are included in the teaching.	*You encourage researchers to think about what science communication is for, what strategies we could use for that and, again, how could we know we have achieved our goals, how we evaluate them.* (Interview 14)
The training model includes a multidisciplinary teaching approach to fully understand the complexity of the relationships between science and society.	*You can also provide them with an understanding of how science communication works more or less, so that they can refer to professional science communicators and carry out this work together, that's sort of what I was teaching my PhD students.* (Interview 1)
All the above-mentioned elements are thought to be combined with a practical approach.	*We organize an intensive program with a mixture of theory and practice, because you need to learn some things and then you need to practice that theory and what we try to do is balance the theoretical with the hands-on skills.* (Interview 21)

Throughout the interviews, we found references to teaching practices to "*make scientists understand the importance of science communication*" (e.g., Interview 2) and reflect on the relationships between science, society, and communication (e.g., Interviews 1, 3, 4, 12, 16, 17). Some interviewees also mentioned the need for "*intellectual context*" (e.g., Interview 4), "*critical reflection*" (e.g., Interviews 3, 4), or a "*conceptual or theoretical approach*" (e.g., Interviews 11, 16) to train scientists in science communication.

In addition to this, one of the academics interviewed (Interview 9) talked about the need to make scientists aware of the potential "*benefits*" of science communication as something that should be included in science communication courses.

The purpose, that is, the different objectives or strategies of science communication, and the evaluation of science communication activities, was also mentioned in some interviews (e.g., Interviews 14, 22) as an aspect that should be included in scientists' training.

A "*multidisciplinary teaching approach*" to fully understand the complexity of the relationship between the science and society relationship is mentioned in some interviews (e.g., Interviews 1, 12). Indeed, one of the interviewees refers to science communication as a multidisciplinary discipline, so that throughout the training, researchers learn how "*to carry out this work together*" (Interview 1). In this way, learning and understanding how different disciplines work together will continue in the researchers' activities beyond their training.

Furthermore, one of the interviewees specifically mentions that "*scientists need an understanding of the public as much as the public needs an understanding of science*" (Interview 22). This, again, is aligned with the idea of science communication as a multidisciplinary and reflective field. During the interviews, this kind of approach is usually mentioned as a "*mixture of theory and practice*" (e.g., Interviews 2, 21) course which is mainly included in undergraduate science communication programs (N = 10) rather than in specific workshops (N = 4). This suggests that scientists should learn about and experience all the elements mentioned above, but combine these with a practical approach to acquire the practical skills needed to practice science communication.

The main obstacle in offering this kind of course is that more time is needed than for practical approach learning, which makes it difficult to offer a reflective approach in a one-day or half-day workshop. However, a reflective approach to science communication is of great interest for undergraduate students of science, not only to understand the science–society relationship, but also to place themselves as future researchers in this scenario.

3.1.3. Disruptive Model

On five occasions in the 26 interviews, we found mentions of what we called the "disruptive model of science communication teaching". These were references to educational practices that address and promote structural changes to the traditional science–society relationship, particularly in the traditional role of researchers (e.g., Interviews 1, 3, 5, 7, 26), but also in other groups of social actors (e.g., Interviews 3, 5, 7, 26), and in the way scientific knowledge is produced (e.g., Interviews 5, 7, 26). Table 6 summarizes the main findings of this model:

One of the interviewees referred to the kind of teaching approach in which the traditional way of conducting science is described as the "*destruction of science*" (Interview 1). In this respect, the way knowledge is produced and the role of the researcher are key concepts around which the teaching of science communication revolves.

One of the teachers specifically mentioned changes in the public's willingness to play an active role in science production, and how citizen participation can directly affect the way scientists conduct their research and produce related communication (Interview 3). One interviewee also mentioned "*the right of citizens to have a say in the definition of the research agenda itself*" (Interview 5) as something that has to be considered in such courses.

"*Knowledge co-production*" (e.g., Interviews 1, 3), the "*roles played by different public*" or specific societal actors (e.g., Interviews 3, 5), "*public engagement*" (e.g., Interview 7), "*citizen science*" (e.g., Interviews 3, 7), "*responsible research and innovation*" (e.g., Interviews 1, 5, 7, 26), and the "*democratization of science*" (e.g., Interviews 7, 26) are concepts that emerge from the interviews in relation to this model.

This approach to teaching science communication was considered especially important in relation to communicating the "*controversy*" (e.g., Interview 5), the "*limits of science*" (e.g., Interviews 5, 7), and the "*uncertainty*" and the "*ignorance*" (e.g., Interview 7).

Table 6. Summary of the main findings of the disruptive model.

Main Finding	Literal Text Examples from Interviews
The teaching is focused on the way that scientific knowledge is produced and the derived changes in the researchers' role.	*The way to teach this would also involve like a "destruction of science" for scientists. Because they live in bubbles, they think that their way is the only way to achieve the truth. Many scientists are still under this delusion, so it would be interesting to actually bring in some social science content to reflect on ways to produce other kinds of knowledge and possible interactions with science, society, politics, etc.* (Interview 1)
The involvement of non-experts in the production of science is a key central aspect of this teaching model.	*We have already begun to talk a lot about models of involvement. It means, for non-expert people to learn with scientists and for scientists to learn with non-expert people.* (Interview 26)
This approach is considered especially important to communicate controversy or uncertainity.	*When you communicate science, you must also always communicate the controversy, the limits of science, as well as the possible impact of your research and what it might achieve in the future. So it's not only about communicating science as a body of knowledge, it's not only about educating the public about a body of knowledge, it's also about the processes of science and science as a human endeavor, with its connections to society, with its limits as an institution, as policy, and in the dimension of the impact it has on society.* (Interview 5)

The disruptive model is based on instructing scientists in the structural changes currently taking place in the production and management of scientific knowledge. This model is closely linked to the reflective model because, without reflection on the objectives of science communication and the interactions between science and society at different levels, it is impossible to even begin to talk about structural changes. The disruptive model can be seen as a step beyond the reflective model.

3.2. Teaching Science Communication as a Profession

From our analysis of the interviews, we have identified two models of teaching science communication as a profession which we have called the professional model (subdivided in theoretical and skills-based learning) and the research model. Table 7 summarizes them, and the findings and frequencies of this dimension of study from all the interviews.

3.2.1. Professional Model

This teaching model of science communication as a profession is based on learning processes that combine the basic skills a communicator must have (such as writing, video editing, social media networks, and interview procedures) with the theoretical models and frameworks of science communication.

We have subdivided this model into two approaches (skills and theory) because, having analyzed the interviews, we saw that the interviewees differentiated between the two learning corpora as pillars of science communication. On every occasion, however, the interviewees ended up mentioning both approaches as necessary elements to complete the training of competent scientific communicators. Notwithstanding, in this section, we present both subcategories separately, as there are specific considerations of particular interest that we wish to analyze for each of the teaching proposals.

Table 7. Models of teaching science communication as a profession identified.

Identified Model	Identified Approach	Findings	Frequency
Professional model	Theoretical approach	Refers to an educational model in which different theoretical models of science communication are taught, as well as historical review and changes in the science–society relationship.	18/26
	Skills-based approach	Refers to an educational model in which the skills and tools needed to deal with practical work in the field of science communication (writing, video editing, social networks, how to interview, etc.) are taught.	12/26
Research model		Refers to an educational model in which the concepts, methodologies, tools, and skills needed for science communication research are taught.	5/26

Theoretical Learning Approach

This learning approach includes teaching different theoretical models of science communication, as well as historical background, and a reflection on changes in the nature of the science–society relationship and of science communication itself (see Table 8).

Hence, the "*nature of science*" (e.g., Interviews 1, 4, 5, 14), the "*nature of society*" (e.g., Interviews 4, 10, 14), and the "*science-society relationship*" (e.g., Interviews 1, 4, 5, 10, 14, 17, 22) are key elements that a science communicator has to understand to be able to properly do their work.

This approach also includes the entire conceptual and theoretical framework of science communication. It means incorporating the "*history of science communication*" (e.g., Interviews 8, 17), "*public understanding of science*" (e.g., Interviews 17, 22), the "*science of science communication*" (e.g., Interview 22), the "*theory of information*" (e.g., Interview 15), and the "*philosophy of science communication*" (e.g., Interview 6) into science communication training. In this regard, one interviewee states: "*It's not enough for them to learn how to write or how to produce social media or whatever, though they have to have that; what they really need is to be able to reflect, to become professional*" (Interview 18). This aligns with our definition of the professional model at the beginning of this section.

One interviewee also considered that "*a broad understanding of science communication as a profession*" (e.g., Interview 1) should be included in this teaching model. Indeed, the adjectives *interdisciplinary* and *multidisciplinary* appear throughout the interviews as a differential element of science communication and, therefore, of its teaching.

Moreover, aspects that refer to the changes in the science–society relationship (e.g., Interviews 1, 5, 14, 17) and the ways in which scientific knowledge is produced (e.g., Interview 14) and science and technology are regulated (e.g., Interviews 1, 17) also appear throughout the interviews as elements for consideration in the training of science communicators. In this respect, "*public engagement*" (e.g., Interview 17) appears as another theoretical approach worthy of inclusion in the professional teaching of science communication.

Also, regarding this science–society relationship, some interviewees highlight the need of addressing ethical aspects of science communication during professional training.

Table 8. Main findings of the theoretical learning approach.

Main Finding	Literal Texts from Interviews
The conceptual and theoretical framework of science communication is a fundamental knowledge corpus of this approach.	*Formal education at master's degree level, for example, is also a form of education in understanding society, in understanding science as a social system, and so on. In a master's program [. . .] there should always be space for historical, philosophical, ethical, ideological, sociological, etc., dimensions of the relationships of science and society to be considered.* (Interview 22)
This approach emphasizes the understanding of key theoretical concepts (e.g., the nature of science, the nature of society, and science–society relationships).	*This training needs more intellectual context and encourages the students to reflect on the nature of science and the nature of society and the nature of that relationship between them. With the idea that, through that sort of critical reflection, you become a better communicator, you've got to understand your audience and you have to understand the nature of your relationship with the audience to communicate better.* (Interview 4)
This approach emphasizes the multidisciplinarity around science communication.	*I think it's necessary to have a multidisciplinary approach, which means not only science, but also sociology, ethics, communication and so on.* (Interview 12)
A deep understanding of public engagement is a key aspect of this learning approach.	*There is a clear trend in the direction of participation, that the relationship between science and society must be seen as a bidirectional relationship, as an ethical contract between the science communicator and the public. This contract means that you must consider the needs and expectations of the public and their right to the truth, their right to in-depth communication of science. All this should be taught at master's degree level.* (Interview 5)
Ethics of science communication are also included.	*And then there is something else that I don't think we teach at all and that we should be teaching more and more, which is ethics, ethics for communicators.* (Interview 15)

It is interesting to note that a number of interviewees criticized the educational model which focused more on the development of the scientific communicator's practical skills (e.g., Interviews 4, 13). These interviewees felt that a master's degree focused on training future professionals in this field should focus mainly on more theoretical and rational aspects than on developing communication skills. On the other hand, another interviewee talked about students' expectations of a mainly practical approach on a master's degree course:

> *Students are sometimes a bit disappointed because they think that these programs are aimed at the profession of science communicator, in the sense that we will teach them how to put on a science exhibition, make a science activity for children, or write a news article with a scientific theme, and sometimes they are disappointed that we are too theoretical.* (Interview 23)

Finally, one interviewee mentioned the lack of standardization in science communication master's degree programs. This interviewee believed there is a need to set up a core of basic theories or a corpus of knowledge to make sure that everyone on a master's degree program in science communication ends up with the same (or a minimum) set of skills and theoretical knowledge.

> *We don't have an agreed curriculum, at least to the extent where we say, are we all teaching the same main theories? Are we making sure to include certain methodologies? Survey design, evaluation, front-end and impact evaluation, whatever.* (Interview 13)

Indeed, this interviewee considers that the lack of standardization between master's degree programs results in a huge diversity of training programs and fails to ensure that all communication professionals share the same skills and knowledge.

Skills-Based Learning Approach

Of the 26 interviewees, 12 referred to teaching programs in which necessary skills are taught in order to deal with science communication professional work. The type of skills referred to by the interviewees can be hard or technical skills, soft skills, or conceptual skills. Table 9 summarizes the main findings of this approach.

For example, the following were some of the technical skills identified as necessary for scientific communicators during the interviews: how to take "*videos and photographs*" (e.g., Interview 3), how to "*use social media*" (e.g., Interview 3), how to "*manage a website*" (e.g., Interview 3), how to "*make radio programs*" (e.g., Interview 17), and how to "*make a podcast*" (e.g., Interview 8).

One interviewee mentioned specifically these kind of hard skills as "*the first thing you have to teach to a professional science communicator*" (Interview 15). This suggests that there are more skills, in addition to these technical ones, that science communicators must learn. For example, soft skills such as how to talk to scientists (e.g., Interviews 3, 4, 17), how to "*listen*" (e.g., Interview 9), how to "*consult information*" (e.g., Interview 9), how to "*engage in face-to-face communication*" (e.g., Interview 8), how to "*speak in public*" (e.g., Interview 16), how to "*produce different forms of journalistic writing*" (e.g., Interviews 8, 17), or "*how to approach a technology or a scientific discipline in order to learn enough about it*" (e.g., Interview 15).

The idea of science communication as a multidisciplinary profession is mentioned again in some interviews (e.g., Interviews 12, 20, 22, 24). This approach is present during training, starting with the composition of the class group (N = 22), considering it a potential benefit to "*learn from each other*" (e.g., Interview 22) and "*to enrich group dynamics during the formation process*" (e.g., Interview 24).

In addition to the above-mentioned references to practical skills, throughout the interviews we found several mentions of more conceptual skills to be included in science communication training programs for professionals. There are specific mentions of the "*need to understand science, or at least the scientific method, and how science is organized, administered and governed*" (Interview 1) as basic conceptual knowledge for future science communicators. A number of the interviewees also talked about the need to teach "*different communication strategies*" (e.g., Interviews 9, 24), "*ways of engaging the public in science*" (e.g., Interviews 9, 23), and "*how to evaluate science communication activities*" (e.g., Interviews 9, 13, 14, 22).

Table 9. Main findings of the skills-based learning approach.

Main Finding	Literal Texts from Interviews
The technical skills of science communicators are central knowledge of this learning approach.	*When you are teaching SciCom you need to be practical, you need to look at the situations that the students might face [. . .] they are going to have to sit down and talk to scientists, they are going to have to encourage scientists to tell stories about their work, they are going to have to take videos and photographs, use social media and update a website, so there is a whole range of technical aspects of the work that they have to be confident about doing.* (Interview 3)
Soft skills such as active listening, talking to different publics, or searching for information are also included in this learning approach.	*I think a Science Communicator needs to learn the skill of listening and consulting and using that information to help drive communication strategies.* (Interview 9)
Conceptual skills such as basic science knowledge, the scientific method, or communication strategies are also considered key knowledge for this learning approach.	*A SciCom professional needs to be trained in how to develop a good communication strategy, how to evaluate that activity, how to how to gather together everything the scientist needs to get the communication across. They need to be educated in the various forms of science communication available to them. It's not only about disseminating information or performing explosive chemistry experiments in front of the public; there are much deeper, more important ways of engaging the public.* (Interview 9)

3.2.2. Research Model

The training of skills and competencies related to research in science communication was mentioned in five of the 25 interviews. However, we considered the intrinsic characteristics of this focus sufficiently different to warrant our grouping them under a different model (see Table 10).

One of the interviewees talked specifically about "*tensions*" (Interview 23) between master's programs designed to train science communication practitioners and science communication researchers, respectively. This led us to think about two co-existing models of training professional science communicators.

The idea of a hybridization of both the research and teaching models as a necessity for science communication professionals also appears in other interviews. For example, one interviewee cited a need for "*evidence-based practice*" (Interview 16), which means teaching science communication strategies, abilities, and concepts, considering prior research performed in the field. Hence, this model includes not only learning "*how to carry out research*" (Interview 13) but also understanding that "*there are people who are studying science communication to understand what's effective and what isn't*" (Interview 16).

Moreover, a number of interviewees highlighted the need to acquire research skills to be able to "*go into the whys and hows of your science communication practice*" (Interview 14) or "*study the impact of every activity*" (Interview 16). Thus, research skills are useful to be able to define concrete objectives for science communication activities and design effective evaluation strategies (e.g., Interviews 13, 14, 16, 22).

One interviewee even considered that professional training mainly based on research skills was better than practical communication skills-based training.

> *I've seen master's degree programs with no readings, like they did, say, their one year of training and never had a single science communication paper in their hand, they didn't even know there was such a thing as research in this field. So, this is a field in which all that is taught is the practical element. I don't think that's okay.* (Interview 13)

Table 10. Main findings of the research model.

Main Finding	Literal Texts from Interviews
The research model co-exists with the practical model in training professional science communicators.	*I think some tensions exist between these master's degree programs. Those programs are more focused on practical teaching, in the sense of teaching the students to communicate science, versus those that focus on teaching students' science communication research.* (Interview 23)
Research skills are the fundamental corpus of knowledge in this teaching model.	*Learning basis on social research is perhaps the most important thing for professional science communicators, especially if we want to promote science evidence-based practice* (Interview 16)
Learning research skills is considered useful even for future science communication practitioners, not only for those students that are going to devote to science communication research.	*Teaching the science of science communication is also useful for science communication practice. Understanding media studies, evaluation techniques, social science research strategies and all dimensions of science and society are key learning areas for future science communication professionals.* (Interview 22)

However, other interviewees consider science communication research "*just an option*" (Interview 23).

> *All the master's programs here try to strike a balance between research and practice. I think we are trying to cater to both needs and perhaps, I'm not sure that students are satisfied with that. You can be an excellent science communicator without conducting research. Research in science communication is just an option.* (Interview 23)

4. Discussion

This is an exploratory study analyzing teachers' perceptions of science communication training for scientists and professional communicators. The study offers insights into the reality of science communication training in Europe and provides an overview of the current different approaches. However, given that this is an exploratory study, our findings cannot be considered representative of all teaching methodologies and further research is needed. Moreover, to achieve a better understanding of how to improve teaching models, it would be necessary to investigate other perspectives such as those of students and alumni, employers, etc.

4.1. Models of Teaching Science Communication to Scientists

As we have seen, drawing from the interviews conducted, we identified three models for training scientists in science communication:

- *Practical model*: where practical skills such as writing, public speaking, or how to behave in a media interview are taught.

- *Reflective model*: where the background, theory, and history of science communication are taught to enable researchers to understand the importance of science communication and the relationship between science and society.
- *Disruptive model*: where traditional roles of scientific knowledge production as well as relationships and power roles in science are challenged.

These three models are not exclusionary, that is to say, they can coexist and even be part of the same educational program because the objectives they pursue are complementary. These three models can be represented as concentric circles in which one model encompasses the previous ones. The outermost circle offers a more complete view of the science communication landscape and adds a new approach to the scientific process itself, in which science communication is a key question (see Figure 2). By representing this figure with concentric circles, it may be concluded that the largest circle merely amplifies what the smallest includes. Yet, in the case of the disruptive model, it is crucial to value the groundbreaking character of the model, which questions the way science is currently carried out and proposes new participatory forms in which science communication becomes a main element.

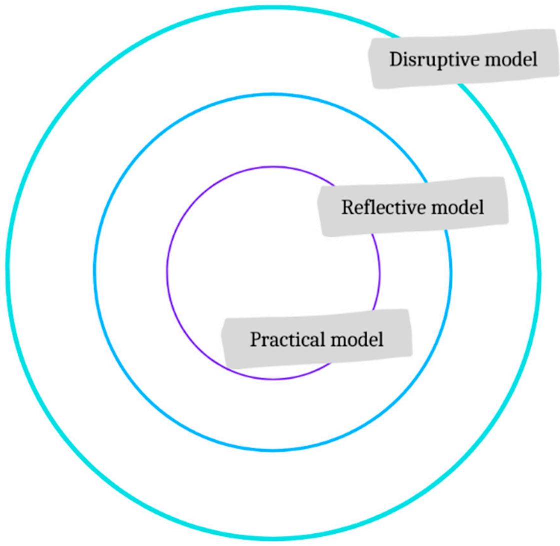

Figure 2. Models of teaching science communication to scientists.

Researchers are growingly present in the public communication of science, either in public-science-related debates, as sources of information or actively participating in outreach activities, such that communication skills can be considered part of the necessary skillset of a scientist. Furthermore, in Europe, a more open and participatory model of scientific production is being promoted, in which communication plays a key role. Hence, the promotion of reflection on the science–society relationship among researchers could help prepare future generations to carry out participatory processes. Such a training could also prepare scientists to better understand different publics and the potential benefits of citizen integration in science production.

It is important to consider the fact that, in the case of short-term educational courses (e.g., workshops), models with more ambitious objectives such as reflection or disruption are much more difficult to carry out. On the other hand, undergraduate science programs and master's programs for scientists based on the latter two models could easily be implemented in several teaching sessions over a longer period of time (thus allowing for reflection). In these latter cases, an educational model based on workshops can serve as a trigger or starting point for deeper reflection.

4.2. Models of Teaching Science Communication to Professionals

Drawing from the interviews conducted, we identified two different models of training or educating science communication professionals:

- *Professional model*: this model is subdivided into two different approaches—theoretical (historical review, understanding of the science–society relationships, etc.) and skill-based (writing, audiovisual, etc.). However, both approaches coexist in teaching programs.
- *Research model*: where tools, skills, concepts, and methodologies for science communication research are taught.

As we can see from Figure 3, the three main corpora of knowledge identified as necessary to train future science communication professionals are represented on three axes. As we move away from the center, we give more priority to one of the three bodies of knowledge. The professional model gives more weight to the teaching of practical skills and theory than to research, whereas the research model gives more weight to the teaching of theory and research skills.

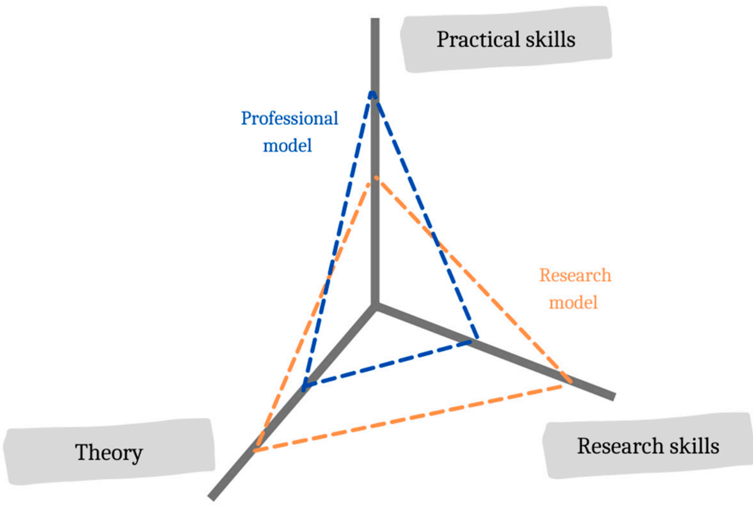

Figure 3. Models of teaching science communication to professionals.

We can move a teaching program along the axes to find all varieties of science communication teaching approaches for future professionals. Some will have a clear focus on professional practice and others on research, with the position of each training program on the axis being determined by the program's educational objectives and the competencies it will develop. A science communication professional must have a basic theoretical knowledge of the field, and therefore an educational model based solely on practical skills would not be adequate.

The four areas of knowledge (science, educational studies, social studies of science, and communication studies) needed for science communication training identified by Mulder et al. [23] can easily be incorporated into both models, as well as training in the systematic assessment of science communication activities [32,33]. This last approach will be taught in greater depth in the research model, however.

Research training in science communication teaching programs is less common, but it is essential if we want to promote evidence-based science communication. According to Eric Jensen et al., in practice, evidence-based science communication should combine professional expertise and skills with the best available evidence from systematic research [56]. Future communication professionals need to understand research methodologies to evaluate their own communicative actions.

Currently, particularly in Europe, there is a trend towards open science and social participation in the production of knowledge; the figure of the professional communicator will be even more necessary. It is not difficult to imagine that institutional actions promoting multidisciplinary collaboration between communication, outreach, or public engagement departments and research groups will be needed to enhance the effectiveness of this kind of research. In this scenario, scientists with an in-depth understanding of the science–society relationship and good communication skills will be highly valued. Science communication training, therefore, has much to offer.

Practical knowledge is essential but, at the same time, reflection and in-depth knowledge of the theory and a comprehensive understanding of science communication research are also required. The coexistence of these different models responds to the multiplicity of teaching objectives, which in turn respond to contextual needs.

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