Science Communication Research: an Empirical Field Analysis

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Executive Summary

This study provides both an empirical analysis of strengths and weaknesses of research in the field of Science Communication, and a reflection on its future needs and perspectives.

This study of Science Communication Research (SCR) triangulates a bibliometric and content analysis of approx. 3,000 journal papers with a multi-stage panel study and a review of grey literature spanning four decades. Quantitative findings from the journal analysis (e.g. about disciplinary contexts or topics, research methods, data analysis techniques used) were considered by a panel of 18 science communication researchers in a multi-stage series of qualitative interviews. These experts represent the international and disciplinary diversity of the research field, including past and present editors of the most relevant journals of science communication, and the majority of the most often cited science communication scholars.

Previous approaches to systematically investigate the research field, include the editorial process of collecting 79 *Major Works* on the public communication of science (Bucchi / Trench 2016a), and the U.S. National Academy of Sciences report on "Communicating Science Effectively" (2016).[1, 2]

Science Communication Research Maturing as an Academic Field

The number of science communication papers in academic journals has increased significantly over the past four decades, especially research studies, and particularly in the last 15 years. The number of countries and institutions contributing papers is also increasing, and more papers are based on international and national collaborations.

Many experts see both increases in the combination of a sign for SCR to have matured to a stage where it is now its own academic field.

Science communication is as pluralistic in its research as it is in practice. The mix of institutions, techniques and disciplines contributes to its diverse status, and often a perceived absence of a clear theoretical framing, as confirmed by many of the expert statements in this study.

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1 Research attempts in the USA to automatically analyse search results on Google Scholar covering no less than 471 different journals, were not pursued further. (see R. Borchelt's conference presentation (2012): "The Science Communication Research Literature Mapping Project." http://www.slideshare.net/OPARC1/firenze-phd-slides (accessed 3 May 2020). Considering the variety of scholarly publications sporadically dealing with science communication research, such big-data approaches nonetheless provide opportunities for both deepening and widening the insight into SCR publishing at large.

2 There is furthermore a bibliometric analysis of journal papers conducted by Günther&Joubert (2017). The data analysed there, is included in the larger sample of this Research Field Analysis here. Similarly, the categories analysed (authors' gender and the geographical location of their affiliation) are also included in the 21 variables investigated in our study.
Guenther, L. and Joubert, M. (2017). "Science communication as a field of research: identifying trends, challenges and gaps by analysing research papers". *JCOM* 16 (02), A02. https://doi.org/10.22323/2.16020202 (accessed 10 May 2020)

Anglo-American Leadership

Like other academic fields, science communication research is mostly published in English-language journals. This gives authors from North America, Europe and the United Kingdom, a natural advantage for the academic publication of science communication papers. There are relatively few publications from countries outside North America and Europe, with comparatively low numbers particularly for low-income countries.

While this imbalance reflects language and population levels, another explanation is the number of established science communication research institutions in the USA and UK. Nine of the first ten most active research institutions are U.S. universities. Even though the distribution can be considered a 'long tail pattern' (i.e. a few very active institutions and many equally average ones)[3], there are disproportionately fewer SCR 'hubs' worldwide. It is therefore all the more important to mention Germany as a notable exception. Such permanent structures are emerging while this report is being produced, notably at Hochschule Rhein-Waal, HSRW (NRW) and Karlsruher Institut für Technologie, KIT (Baden-Württemberg). Here permanent university chairs with specific degree programmes have filled a void which had been discussed in the practitioners' community and academia in general for decades. Prior to the establishment of these academic structures, a long list of universities had supervised / produced dozens of PhD and final theses with close reference to SCR. Comparatively few of these have reached international visibility, as the bibliographic analysis in this study shows. One major cause for this may be the language barrier, and the dispersed nature of disciplines and scholarly publishing in this field.

In general, centres for SCR with long-term structures and thus a 'critical mass' of personnel, are still rare, even from a global perspective. Worldwide, there is otherwise only a handful of such hubs: the Centre for the Public Awareness of Science (CPAS) at the Australian National University (ANU), the Centre for Science Communication at Otago University in Dunedin (New Zealand), the Centre for Life Sciences Communication at the University of Wisconsin-Madison (USA), and the Chinese Research Institute for Science Popularisation (CRISP). Several UK universities have established Science Communication departments such as Imperial College and University College in London, the University of West England (UWE), the London School of Economics and further universities in Manchester, Sheffield, Edinburgh, or Aberdeen, yet mostly without institutional structures, research chairs, etc. A comparatively large Institute for Public Communication of Science and Technology was established in Brazil. Further smaller hubs to be mentioned: Stellenbosch, Barcelona, Trieste, Dublin, St. Petersburg, Guadalajara, Mexico City, etc.

In addition to its existing SCR hubs at several universities, the USA has furthermore developed additional trans-institutional research (funding) initiatives, mostly driven by the National Academy for Sciences, Engineering and Mathematics (NASEM), the National

[3] The term "Long tail" has been a common expression in statistics for decades. It became popular even among lay audiences by Chris Anderson's article in *Wired*, followed by a book: *The Long Tail: Why the Future of Business Is Selling Less of More.*

Science Foundation (NSF), and the American Association for the Advancement of Science (AAAS), which can be expected to strengthen the already strong U.S.-American position in this field further. Partly comparable are the initiatives by German academies of science to produce White Papers on science communication and hence also its research. These initiatives, however, are mainly analytical and do not include significant funding schemes.

Typical for both the USA and the UK, are SCR initiatives provided by private foundations such as the Wellcome Trust in the UK or, in the US, the Sackler Foundation, Burroughs Wellcome Fund, Rita Allen Foundation, William and Flora Hewlett Foundation, Gordon and Betty Moore Foundation, etc.

Considering that such philanthropical research funding traditions are comparatively uncommon outside of the Anglo-American world, similar SCR resources in Europe can only be expected to come from governmental funding bodies. Private foundations which have previously provided dedicated funding schemes for SCR, include Stifterverband für die Deutsche Wissenschaft, Volkswagen Stiftung, Robert Bosch Stiftung, Klaus Tschirra Stiftung, and Körber Stiftung, all of which, however, have provided significantly smaller funds than many of their international counterparts. Moreover, foundation-funded programmes in Germany had a rather practical instead of a research focus, e.g. STEM uptake or Science Journalism. The first funding programme explicitly addressing the "Science of science communication" and the transferability of research into practice, was "Science communication cubed", a call launched by the Volkswagen Foundation in February 2020.[4]

Grand Challenges

The results from this study indicate that SCR is facing several 'grand challenges'.
The four most pressing ones are the following:

1) **A research field mostly limited to one-off studies:** Compared to the large number of very case-specific studies about the use of certain tools in certain cultural contexts for certain research areas, experts interviewed in this study and also previous analyses unanimously see a need for more longitudinal, comparative and systemic research.

2) **Caught in established disciplinary structures and habits:** As shown in this study, SCR is multi-disciplinarily fragmented by the variety of theories used. Scientific communities such as in Media Studies or Marketing, Sociology of Science or Social Psychology, often use different jargon, and present their results at different conferences and in different journals. The opportunity of an interdisciplinary integration of the different research traditions has not been seized yet.

[4] "Science Communication Cubed – Science of Science Communication Centers". VWS website. https://www.volkswagenstiftung.de/en/funding/our-funding-portfolio-at-a-glance/science-communication-cubed%E2%80%93science-of-science-communication-centers (accessed 3 May 2020)

3) **Lack of transfer between scholarship and practice:** In addition to these inner-academic challenges, SCR is limited by a second disconnect—between scholarship and practice. Neither takes sufficient notice of the other's priorities, challenges and solutions. After debating this at three "Science of Science Communication" Conferences[5] in Washington over the years, the USA pioneered a tandem initiative called "Research Partnerships"[6] in winter 2017. Challenges and solutions to align SCR better with practice, finally led to the world's first Symposium on "Evidence-based Science Communication"[7]. All of the above-mentioned initiatives have identified a direct result of the double-disconnect: a lack of application and implementation, experimentation and applied research.

4) **Lack of diversity in research topics:** SCR insufficiently acknowledges certain publics and actors, e.g. the science communication practitioners themselves; people generally uninterested in science; partisan and influential pressure-groups and 'deniers', etc.

Research Gaps

Experts interviewed and research literature analysed in this study, show how SCR does not sufficiently address the challenges above. The following four main clusters of research gaps have been identified:

1) **Changing information behaviour and attitude-formation:** Systemic changes in the digitalised media environments are not yet sufficiently understood, including the recent debates about 'post-truth' and data-driven mass-manipulation. In general, science communication often appears more relevant when topics are more controversial. Yet this is not sufficiently addressed by SCR in general. This study has identified research gaps in understanding the formation of societal values and public trust with regard to science and innovation. Research topics could for instance be communicating either consensus or uncertainty, responding to misinformation and framing effects.

2) **Rapidly changing media systems:** Digitisation brings about not only new means and tactics but even entirely new actors in communication such as journalistic media platforms which are not 'journalistically independent' in a classic sense. Formerly established intermediaries are replaced. SCR should analyse these systemic changes as well as suggesting and experimenting with alternative models and practices.

3) **Evaluation of policy impacts:** How to measure and compare the impact of communication on science and innovation policy and regulation is another research gap.

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5 http://www.nasonline.org/programs/sackler-colloquia

6 While AAAS recently launched an online platform to bridge this research gap (https://www.trelliscience.com), the U.S. National Science Foundation initiated the so-called "Research & Practice Collaboratory", which aims to address the scholarship/practice disconnect with a comprehensive "Toolkit", albeit with a certain emphasis on formal and informal science education.

7 The so-called 'Bellagio Conference' (http://www.scicom-bellagio.com) was also funded by a U.S.-American foundation (Rockefeller), but hosted in Europe (Italy).

This should include not merely institutional or journalistic impact but also political influence from organised interests such as pressure groups and lobbyism. Particularly for statutory regulation processes (e.g. regarding the question to which extent CRISPR technology will legally be treated as mere genetic modification) there is a lack of both methods and impact measurement for formal science engagement such as citizen participation processes from an agenda-setting perspective.

4) **Communication Governance:** Considering that science policy increasingly requests specific forms of communication as part of their funding and / or assessment of research proposals and results[8], scientific institutions increasingly discuss science communication issues from a governance perspective, both regarding its institutional structures and institutional cultures. This raises the question of how such a communication, which becomes an integral part of academic conduct itself, should be managed and monitored, e.g. regarding incentives and recognition, and how its impact can best be assessed.

Research Recommendations

This study leads to eight Research Recommendations. In order to structure the research topics to be addressed, the study lists potential topics for future funding schemes directly related to the Research Gaps and Grand Challenges identified in the data.

1) Greater encouragement should be given to research topics beyond public understanding, attitudes or media studies, such as responding to the replacement of intermediaries. More research is needed about the nexus between science and the changing political and social landscapes. Neglected SCR topics are summarised above under “Research Gaps” above, and described in more detail in the chapter on “Research Recommendations” below.

2) More longitudinal studies that examine changes over time, and more experimental field research, would strengthen science communication and help establish it as an academic field. Only a minority of longitudinal studies so far focuses on audiences and actors.

3) Science communication research needs to examine specific groups more closely, breaking down the amorphous ‘general-public’ into more meaningful stakeholders such as marginalised or science-sceptic audiences, indigenous groups or senior citizens. Also science communication practitioners themselves are hardly being researched at all.

4) Biology and ecology have dominated disciplinary focuses in SCR for decades—a trend which has recently even increased. This study therefore recommends encouraging research that looks at the entire spectrum of (not just natural) science and (not just

8 e.g. “Responsible Research and Innovation” (RRI) for the European Framework Programme; “REF” (Research Excellence Framework) for UK science funding; Transfer projects (“Transferprojekte”) by the National Science Foundation in Germany (DFG), etc.

technical) innovation. This would include contributions from the humanities, arts and social sciences.

5) Theoretical foundations in SCR need to be developed further, which will require much closer global and cross-cultural research collaboration. Various disciplinary strengths could be combined into more sophisticated mixed-methods approaches. National research could learn from investigating the diversity of communicating science and innovation. Theory and practice could be integrated e.g. in future study design, while also increasing the replication of international SCR approaches.

6) Mixing research methods and using new tools needs to be encouraged in SCR. Data-mining for instance offers a tool-set which is hardly used in SCR, e.g. for analysing large data sets in areas such as social media.

7) While SCR mostly investigates single case studies, experts request a wider systems approach to understand how contents and channels, actors and audiences interrelate.

8) Science communication research is lacking collaboration across cultures and continents or even just beyond national borders.

9) A significant number of researchers furthermore seems to lack methodological skills, particularly in statistics. Knowledge transfer and capacity building in this respect could be a good starting point for international collaborations.

Introduction

The aim of this study is to identify and compare international trends and gaps in science communication research[9].

This study has triangulated a bibliometric and content analysis of 3,000 science communication journal papers with a multi-stage panel study and a review of grey literature.

Science communication research is, just like science communication practice, a diverse field when it comes to the researchers' disciplinary backgrounds and their fields of expertise, their target groups, methodologies and publication outlets. Being aware that it is difficult to capture all of the developments in the research field over the last decades, this study aims to draw conclusions by approaching the issue from a number of distinct perspectives. Applying methodological triangulation, it examines different data sources, namely published academic papers, grey literature and expert statements, to shed light on the general trends and gaps, needs and opportunities in the research field.

The study design combines a multi-step expert survey with a bibliographic and content analysis. As shown in Figure 1, the expert survey consists of three parts of which two are interlinked with the bibliographic analysis. The bibliographic analysis consists of two parts: the journal analysis and the analysis of grey literature.

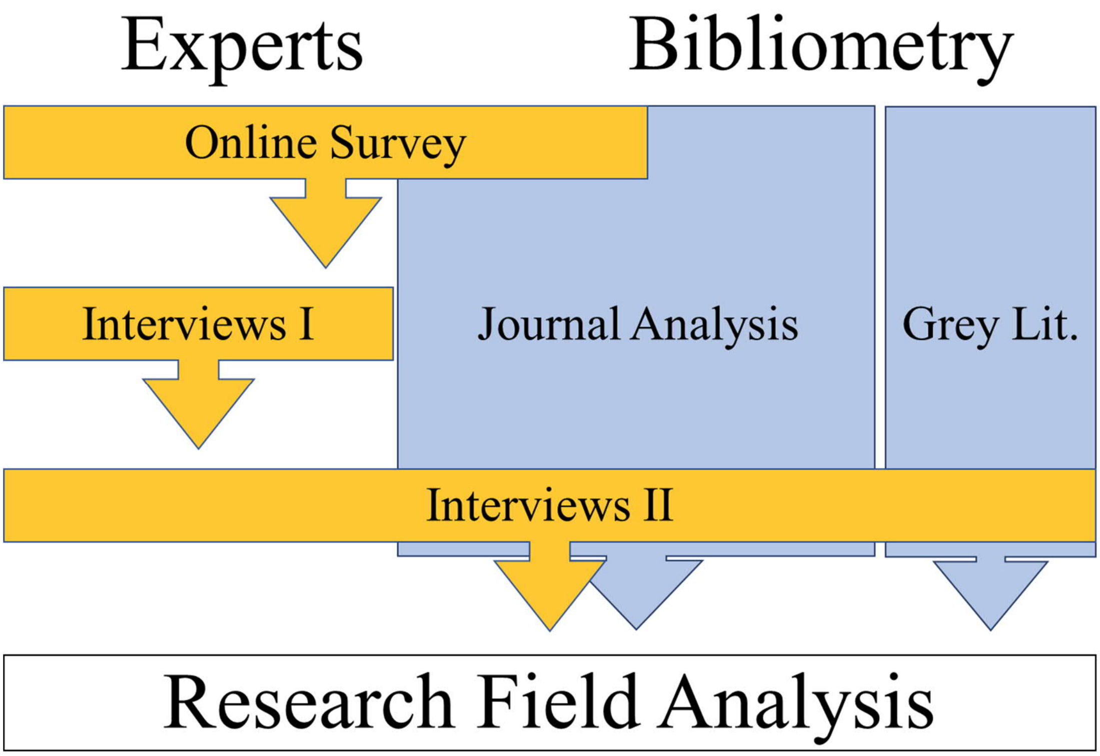

Figure 1: Methodological structure of this Research Field Analysis

9 See the next section on "Methodology" for details as to which instruments considered what as "research"

The study analyses all the articles ever published in *Public Understanding of Science (PUS), Science Communication* (SCX) and *Journal of Science Communication* (JCOM). Many science communication papers are being published in other disciplinary journals, e.g. in the areas of Nanotechnology or Health, and some authors prefer to publish their research in books.

For the journal analysis, the study analyses a sample that is as representative as possible for the field. The scope of the literature analysis was limited to peer-reviewed publications, which excludes books. The decision to focus on the three science communication journals is based on the results of the first stage of the expert survey (for a detailed description of survey methodologies used, see pp. 11-13).

The relevance of highly visible journals and magazines such as *Nature*, *Science* and *Scientific American* was the reason to include these also in the analysis. Thereby, the analysis also provides insights about topics covered in outlets which target a broader scientific community or even popular science audience rather than just the science communication community specifically. Additionally, this study analyses “The Public Communication of Science - Major Works in Public Communication of Science” (Bucchi / Trench 2016a) hereafter referred to as the *Major Works*, which also provides insights into other publication types relevant to science communication research beyond the above-mentioned publications.

Methodology

Expert Survey

An international sample of experts in the field of science communication was selected in cooperation with the German Federal Ministry of Education and Research (BMBF) and its project management agency DLR PT.
In addition to experts identified from the global science communication research community, the sample included representatives from academies of sciences, funding bodies, associations and learned societies, as well as editors of science communication journals.[10]

The experts were invited to take part in all three phases of the expert survey. A brief outline informed them of the context, aims and process of the study.

Online Survey

The online survey had the objective of identifying the most important publication outlets for science communication research. Experts were provided with individual tokens to access the survey. After two reminders, 36 experts submitted their answers resulting in a response rate of 59%.[11]

A list of 23 journals was provided, with the option to add journals that the experts deemed to be important but had not been included in the provided list of journals. The journals provided were selected by researching the journals with the highest impact factors when searching for the term science communication in a scientific journal database. In addition, we used the most often quoted standard publication in science communication *The Public Communication of Science* handbook, (2nd edition, Bucchi / Trench 2016b) as a resource and added all journals to our list that had at least two articles included in this publication.

The results (Figure 2) show that the three science communication journals *Public Understanding of Science* (PUS, 94%), *Science Communication* (SCX, 83%) and *Journal of Science Communication* (JCOM, 78%) were the journals that most experts rated as being most significant for science communication research. The other journals seem to be important only for some experts, which most likely was due to their respective research focus. Hence the three journals chosen for the bibliometric and content analysis were PUS, SCX and JCOM.

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[10] In November 2016, personalised invitations were sent via email to 61 experts. Two experts declined and were replaced by experts with a similar expertise from similar geographic regions.

[11] One expert only added a comment but did not select any journals.

Two experts each named the following journals in addition to the provided list:

- Research for all (launched 2017)
- New media and society
- Journal of Research in Science Teaching (JRST)
- Environmental Communication

One expert each named the following journals in addition to the provided list:

- Social Epistemology
- International Journal of Science Communication - Part B
- Gateways
- Science
- Proceeding of the Academy of Sciences
- Nature
- Science Policy
- Climate Research
- Public Relations Review
- Journalism and Mass communication quarterly
- Journal of Research on Science Education
- Journal of Health Communication
- Science, Technology and Society

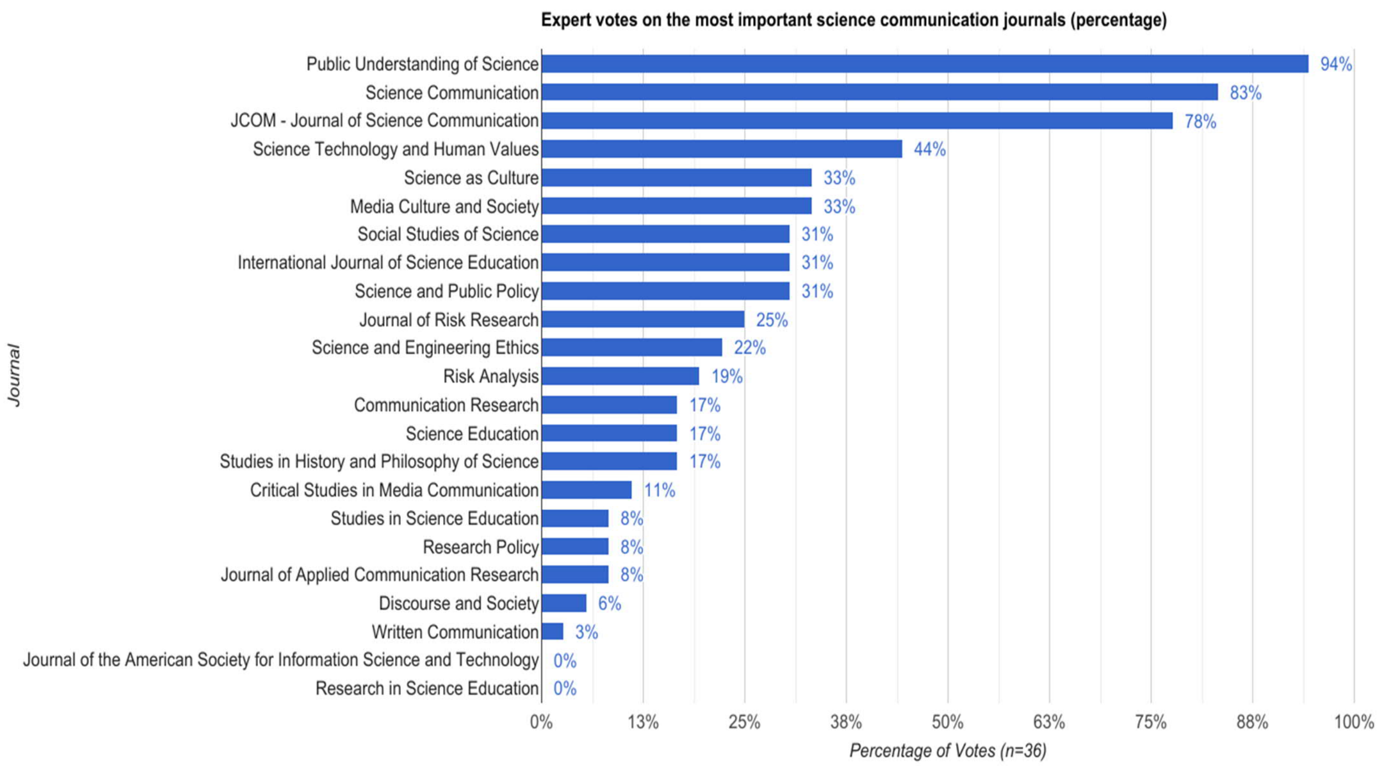

Figure 2: Responses to the online survey asking experts to identify the journals they find most important for science communication research (n=36)

Journal Analysis: *PUS, SCX, JCOM*

It was decided to analyse the whole population of articles published in *Public Understanding of Science* (PUS), *Science Communication* (SCX) and *Journal of Science Communication* (JCOM). All articles ever published in the three journals up until the end of 2016 (in the case of SCX since 1979) have therefore been included in the analysis.

We decided not to rely on author-selected keywords for our content analysis, following Emma Weitkamp's (2016) argumentation and analysis. As Editor of JCOM, she had come to a similar conclusion when she realised that authors had not used article keywords consistently enough to allow a meaningful categorisation. This Research Field Analysis has therefore instead conducted a much deeper analysis by defining specific aspects of interest to be analysed by a team of trained coders.

The variables included the following more basic data:

- Journal
- Title
- Original Publication Date
- Date
- Issue
- Name of the corresponding author and up to four co-authors
- Affiliation of the corresponding author and up to four co-authors (e.g. institutions)
- Country of the corresponding author and up to four co-authors (based on affiliation)
- Abstract
- Gender for the corresponding author and up to four co-authors

Other variables focus more on characterising the article and its content:

- Type
- Context cluster
- Context discipline
- Topic cluster
- Topic detail
- Participants
- Target group
- Research focus
- Research timing
- Research method
- Data analysis method

As this study is focussing on science communication research, only articles that were identified as research studies or systematic reviews under the category "Type" have been analysed in detail. For all other article types, the analysis stopped after their 'type' had been established. Detailed instructions, descriptions of categories and examples were included in the codebook.

Over two months, a team of nine coders was trained. The coders were science communication students at Rhine-Waal University ranging from their second to ninth semester meaning that all of them had academic education in science communication and natural sciences. They were familiar with various different theories and concepts, formats and methods in SCR. Test coding was discussed in the group to make sure the coders received feedback from experienced science communication scholars. This iterative process of testing and debriefing also helped to improve the category descriptions in the codebook and led to some categories being added inductively. At the end, we used a randomised and stratified sample of 130 articles (2 issues from each of the three journals) to determine the inter-coder reliability. Based on the expected number of articles n=1,784 (2002-2016), this is about 7% of the data.

The inter-coder reliability was calculated as Krippendorff's alpha (Table 1). Krippendorff's Alpha is widely regarded as one of the most reliable and sophisticated methods, as it does not only take the raw agreement of coders into account, but also their agreement by pure chance. Generally, values of 0.8 and higher are desired, while values between 0.8 and 0.67 are only defendable in some cases, and values below 0.667 are unacceptable (Krippendorff, 2011).

The values for this intercoder reliability analysis were calculated using the Krippendorff's Alpha Python implementation "fast-krippendorff" (Pln-Fing-Udelar, 2019). As only the presence or absence of certain values for each variable was coded, the nominal metric for Krippendorff's Alpha was used. To further support inter-coder reliability claims, a post-test was conducted in addition to the pre-test. Here the final codings were compared to the original ICR coding pairs, meaning the final coder acted as a third coder.

		Pre-test (2 coders)		Post-test (3 coders)
Tested Variable	**Total**	**Agreement**	**K´ alpha**	**K´ alpha**
Type	130	87.7%	0.81	0.85
Context Cluster	99	60.0%	0.69	0.71
Context Discipline	90	48.5%	0.65	0.63
Topic Cluster	201	64.1%	0.76	0.76
Topic Detail	210	59.5%	0.69	0.68
Participants	80	84.4%	0.76	0.60
Target Group	93	78.5%	0.67	0.56
Research Focus	69	81.5%	0.66	0.69
Research Timing	67	84.6%	0.25	0.43
Research Method	86	90.3%	0.82	0.67
Data Analysis	96	86.4%	0.77	0.72
Gender	3409	96.54%	0.93	-

Table 1: Inter-coder reliability testing using Krippendorff's Alpha

The coders were allowed to code up to three choices for some variables: Topic Cluster, Topic Detail, Participants, Target Group, Research Method and Data Analysis Method. This helps to explain the lower values in percent of agreement. Some coders used all three options and others only chose one or two of the options.

In addition, any disagreement in the categories of variables for topic and context automatically leads to a disagreement in the Topic Detail and Context Discipline variables as the decision in the categories determines the range of options in the sub-categories (for further details, see Codebook as Attachment B).

The variable gender was coded by two additional coders and in cases of disagreement, a third coder made the final decision. It also was the only variable that was tested on the entire dataset, leading to a very high number of coded cases and thus excellent Krippendorff's Alpha score. Since the pre-test was conducted on the full dataset, yielding a sufficiently high score, the "gender" variable was not included in the post-test.

Regarding the Krippendorff's Alpha score, the variable "Research Timing" appears to be insufficient [0,25 (pre-test) or 0,43 (post-test)], corresponding to a low acceptance level. The percent of agreement, however, is 84,6%. The low Krippendorff's Alpha score therefore is due to the dominance of one of the categories, leading to a high probability of agreement by chance. This dominance has an impact on the statistical calculation for Krippendorff's Alpha, resulting in a low score, despite the high level of agreement. This effect has been described in the literature (Feinstein & Cicchetti 1990). Previous test coding, as well as the final results assured us that this effect was not created by a skewed sample.

Once the inter-coder reliability was considered sufficient, and debriefings were implemented, the coders started coding the actual dataset in two steps: First for the period 2002-2016, and then the timeframe 1979-2016. For data analysis and data visualisation, Google sheets, Microsoft Excel, SPSS and Tableau were used.

Journal Analysis: *Nature*, *Science*, *SA, Major Works*

The same coding procedure was applied to articles about science communication from the major scientific journals *Science*, *Nature*, and *Scientific American* magazine, published between 1903 and 2016. The articles were identified by searching for the term 'Science Communication' using the full text search on the journals' websites. The search delivered 330 articles. However, when the coders read the papers they found that 73 were natural science papers and did not actually discuss science communication. The basis for coding decisions of the remaining 257 articles was the description of the categories in the codebook rather than the classification provided by the journals.
In addition, 79 articles from the collection of "The Public Communication of Science - Major Works in Public Communication of Science" (Bucchi / Trench 2016a) were analysed.

In total, 3,133 articles were analysed, including 313 systematic reviews and 1,097 research studies where context and topics were coded. In addition, the 1,097 research studies were characterised with regards to participants, target groups, research focus, research timing, research method, and data analysis.

A summary of the types and numbers of papers analysed is shown in Table 2.

All types - JCOM, PUS, SCX, Nature, Science, Scientific American & Major Works

	JCOM	PUS	SCX	Subtotal	Nature	Science	Scientific American	Subtotal	Major Works	Total
Book Review	21	76	134	231	15	8	0	23	0	**254**
Commentary	251	30	95	376	6	12	3	21	0	**397**
Editorial	56	21	56	133	6	4	0	10	0	**143**
Essay	59	117	126	302	1	5	1	7	41	**350**
Letter	10	8	8	26	13	12	0	25	0	**51**
Literature Review	12	70	117	199	0	5	0	5	2	**206**
Other	10	48	122	180	63	76	1	140	2	**322**
Research Study	137	539	407	1,083	0	0	0	0	14	**1,097**
Systematic Review	30	123	114	267	0	20	6	26	20	**313**
Total	**586**	**1,032**	**1,179**	**2,797**	**104**	**142**	**11**	**257**	**79**	**3,133**[12]

Table 2: Sources, numbers and types of papers analysed through coding of variables

Expert Survey - Interviews Part 1

In a first round, partly in parallel to the online survey, we conducted 33 semi-structured interviews with experienced science communication researchers from around the world (see Attachment A). The interviewees included seven people based in the United Kingdom, four based in Germany and four in the USA. Four people who completed the survey were subsequently unavailable for interviews. We therefore interviewed 52% of the experts originally invited to be involved and 86% of the experts who completed the survey.

During the interviews the experts were asked three broad questions in the initial interview about the respondents' perceptions about science communication research - the trends over the past 30 years, the gaps; and future needs:

[12] This figure logically counts a few publications twice, because *Major Works* also includes journal papers from e.g. *PUS*

Q1. What has been the focus of science communication research (SCR) over the past 30 years? Has this changed over this time?

Q2. Which areas of SCR have been underrepresented in SCR over the past 30 years? What are the reasons for these gaps?

Q3. What should the field of SCR focus on in the future? What are the challenges and what sort of support is needed for that development?

In addition, the interviewer teased out perceptions about topics, methodologies and approaches. All interviews were conducted via phone / video chat between December 2016 and January 2017. The interviews were analysed thematically based on recordings and notes taken during the interviews in order to identify dominant perceptions of the interviewed experts.

It is important to emphasise that the interviews represent the participants' perceptions, which does not necessarily mean that the remarks stand for specific research into the topic by the respective interviewees. Some respondents wanted to make it clear that their perceptions were likely to be coloured by their own specific research interests and experiences.

Expert Survey - Expert Interviews Part 2

In the second round of interviews, the experts were presented with preliminary results of the journal analysis of the three specialist science communication journals: *Public Understanding of Science*, *Science Communication* and *Journal of Science Communication*, which was provided to them prior to the interviews.

34 interviews were conducted with science communication experts from around the world (see Attachment G Expert interview – Part II) via phone / video chat between February and March 2017. This included seven people based in the United Kingdom, four in Germany and five in the USA. These people were all interviewed previously about science communication research trends and gaps over the past 30 years. An additional interviewee, Dietram Scheufele, was only available later and thus added to the second round of interviews.

The experts were asked three reflective questions about the data:

Q1: What interested or surprises you?
Q2: Do you have any explanations for the data?
Q3: What further investigations of the data might be useful?

In addition, as a result from the literature review and other studies, a tangential question was asked about any suggestions the experts might have for better linking science communication theory with practice.

Similar to the process in part I, the interviews were analysed thematically based on audio-recordings, transcriptions and notes taken during the interviews in order to identify dominant perceptions of the interviewed experts.

Grey Literature Analysis

By its very nature "grey literature" is an area that is difficult to define or circumscribe. This makes it difficult to have an empirically sound set population from which a representative sample can be drawn. However, despite the sampling limitations, this does not prevent a systematic analysis being carried out on the texts that have been selected.
The selection of texts was made based on:

- Extensive international expertise within the project team
- Suggestions taken from experts interviewed as part of the project
- Cross-references picked up from within the grey literature itself.

In total there were 22 documents selected from the United Kingdom (UK), United States of America (USA), European Union (EU), Australia, Canada, and South Africa. In addition, 33 German publications were analysed. Publication dates ranged from 2002 to 2016 for the international texts and from 1999 to 2016 for the German documents. Some sources were conference proceedings with brief texts about various talks. Here, those texts within the documents addressing general issues of science communication were included for analysis.

The systematic framework analyses of publications considered the following themes:

- Journals and papers referenced
- Key themes and / or case studies
- Theoretical stances mentioned or used
- Science communication trends
- Research gaps identified

Although not strictly a theme within the matrix, additional further points of interest were also noted.

Results and Discussion

1. Increasing Number of Research Publications

Between 1979 and 2016, the three science communication specialist journals published 2,797 papers of all types. The results for this period were compared with those from 2012 to 2016. Between 1903 and 2016, two of the world's oldest journals, *Nature* and *Science*, published 257 papers on science communication. The *Major Works* included 79 papers. Coders selected one 'type' for each paper. All of the papers, except for the *Major Works*, were also coded according to the gender of the corresponding papers.

1.1 The number of articles on science communication has increased significantly

The first journal dedicated to this subject, *Science Communication*, (SCX) began publication in 1979. Since then two other specialist journals have been launched, *Public Understanding of Science* (PUS) in 1992 and the *Journal of Science Communication* (JCOM) in 2002, and both have increased the number of issues they publish each year. PUS increased from four to six issues in 2009 and then went to eight issues in 2012. JCOM increased from four to six issues in 2016. The number of SCR publications have also continuously increased in *Nature*, *Science* and *Scientific American* (SA). Additional open access publications have emerged in the past few years, yet almost exclusively in the UK. Furthermore the SCR communities in India, China, and Japan have research outlets in their native languages, which mostly go unnoticed internationally however.

1.2 Peer-reviewed research studies make up 40% of all articles

The most common type of paper found in the three science communication journals were peer reviewed research studies[13]. Between 1979 and 2016, the three specialist journals published 1,350 papers in the categories of research studies (1,083) or systematic reviews (267). Research studies have steadily increased as a proportion over time in the specialist journals (particularly with the advent of PUS in 1992), from a median of 24% in 1979-1999 (7 studies in total) to a median of 37% in 2000-2016 (43 studies in total).

Other types of papers published in the three journals include commentaries (13%), which increased in number when JCOM started in 2002. The number of essays (11%), systematic reviews of research (10%), book reviews (8%) and literature reviews (7%) has fluctuated

[13] Peer review refers to a standard quality assurance system in research: prior to publication, each article is independently reviewed by fellow researchers, who possibly also request the author to make significant changes to meet the journal's quality threshold.

throughout the years at relatively low numbers. Systematic reviews of research[14] have steadily declined as a percentage of papers, from a median of 14% in 1979-1999 (6 reviews in total) to a median of 10% in 2000-2016 (11 reviews in total).

The three general journals published 257 articles on science communication over the period between 1903 and 2016, but it is remarkable that not a single one of those were reports on actual empirical research on science communication. Instead they focussed on news, reports and announcements.

1.3 Experts see the rise in research studies as a maturing of the field

Most of the experts (21/34) interpret the increase in empirical research studies (compared to more theoretical reviews or commentaries) as a maturing of science communication in the field of academic research, although some (5/34) thought it might be due to increased funding for issues-based research (e.g. topic- and tool-specific calls such as about the online communication of animal research), and a greater institutional pressure on researchers to publish. As one expert said: “It is good to see [an] increase in international collaboration, though this is not a big surprise with Europe having big research programs. Brussels is pushing for a more international approach to research including science communication, and this may be reflected by your figures” (Michel Claessens, ITER International Thermonuclear Experimental Reactor). They were concerned by the decline in systematic reviews of research (s.a. page 20) which are considered to be the ‘gold standard’ in any other disciplines since they integrate findings from a wide variety (ideally even all available evidence on a certain topic) on a meta-level; especially given the role such reviews play in creating a ‘field of study’ or even a discipline. Such meta-analyses which put individual findings into context, are also known for fostering the transfer of a more relevant combination of results into practice. The experts felt this was due to the lack of funding or academic reward for this sort of research, which obviously exceeds what could normally be done within e.g. a single PhD project. As one expert (Prof. Brigitte Nerlich, University of Nottingham) said: “You don’t tend to get points for this sort of research… [There are] likely institutional pressures against this sort of research.”

1.4 Generally more male authors in SCR, but female researchers are catching up

As long as all countries covered by this study are considered, the mean proportion of male authors (55%) does not divert much from comparable fields of research. This rises to 58% if the count records only corresponding authors (the lead author of a paper).

[14] Systematic reviews are a well-known source for the best available evidence in medical research, yet by far not as common in most other disciplines. Articles coded here as “Systematic reviews” constitute meta-analyses of several (often dozens) of individual studies about a certain topic.

In the last five years, female corresponding authors have overtaken males as authors of research studies (53%) and systematic reviews (52%); and achieved near-parity with the total number of papers contributed (49%).

However, in the three general science journals, male authorship is even more pronounced than in the specialist science communication journals, where males write 70% of articles on science communication.

2. USA and UK Prevail in All Types of Publications

2.1 More than 50% of specialist journal articles have authors from the USA and UK

A count of corresponding authors shows that the USA is responsible for 41% and the UK for 15% of all articles written. Italy came third with 6% (reflecting the fact that JCOM was initiated from Italy) and most of the other 56 countries contributed less than 1%, with none more than more than 4%. The countries and institutions of the corresponding authors for all papers were coded for all papers except the *Major Works*.

2.2 Most authors from developed countries but more countries are contributing

Prior to 1995, fewer than 10 different countries contributed papers to the specialist journals in any one year, but this is increasing steadily and peaked in 2014 with articles from authors from 37 different countries. Over the life of the specialist journals, corresponding authors have come from over one-third of all countries (59/195). But publication is skewed to developed countries: a list of the top 20-ranked countries (which cover more than 90% of all publications) include not a single developing nation but at least two emerging economies: Brazil (1.4%) and India (0.6%).

2.3 Europe has overtaken the US as largest contributor.

Regionally, North America (46%) and Europe (39%) dominate the rankings of corresponding authors for all types of papers in the specialist journals. Asia (4%) and Africa (0.75%) are almost on a different scale.

Europe has increased its share of publications since 1992 (probably reflecting the formation of two new journals of science communication, PUS and JCOM); and figures for the past five years (2012-2016), show Europe (51%) well in front of North America (29%). Germany: 3%.

2.4 Likely causes and impacts

While not surprised at the prevalence of English-speaking countries, some experts were astonished at the extent of US-UK influence. They believed the causes were:

- The geographic location of the journals, and where they were initiated (SCX in the USA; PUS in the UK, JCOM in Italy)
- The difficulty of publishing in English for non-native speakers
- The well-established traditions and institutions for science communication in the USA and the UK
- The size of contributing countries such as the USA, which is the largest country in the world publishing in English.

2.5 The most active institutions are in the USA and the UK

An analysis of all types of papers in the specialist journals confirmed the dominance of institutions in the USA and the UK. Every institution in the top 20 was based in the USA or UK, except for the University of Amsterdam. When limiting the analysis to research studies and systematic review papers, the top 25 list was led by North-American and British institutions, and included only four institutions from other countries: the University of Amsterdam, University of Twente, Aarhus University, and the University of Calgary.

Overall the University of Wisconsin-Madison (UWM) in the USA topped the rankings as the most prolific contributor of all papers (60) including research studies and systematic reviews (44). UWM's dominance is not surprising, said one of the experts, given they have one of the oldest and most active science communication programs in the world.

There is a mix of institutions contributing to science communication research, and it is interesting that no single institution contributes across all three science communication journals. One of the experts, Professor Alan Irwin, said: "It's a field where there are so many different disciplines from psychology to statistical analysis – this is a field that hasn't entirely come together in terms of institutions."

2.6 North America and Europe dominate the general journals *Nature* & *Science*

Contributions in the general journals follow a similar pattern to the three specialist science communication journals analysed above. Authors based in 13 different countries contributed to the analysed papers (n=116) as corresponding or co-authors, and the number of contributing countries has increased over the last decade, peaking at six per year in 2008, 2013 and 2015. While authors from the USA and the UK are the major contributors of science communication papers in *Nature,* Americans largely write papers in *Science* and *Scientific American.* There were no research studies in any of the general journals, and no systematic reviews about science communication published in *Nature*.

3. National and International Collaboration on the Rise

3.1 Single-author papers down, multi-author papers up

The number of single authors publishing all types of papers in the specialist journals is decreasing, with papers from collaborating authors on the rise. While single authors published 56% of papers over the whole study period (1979-2016), the figure for the last five years has dropped to 40%. More authors are now collaborating with others in their own countries (up from 31% to 37%) or with authors from other countries (up from 14% to 24%).

National and international collaboration in research studies or systematic review papers across the specialist journals is stronger than for all paper types, and has increased in the past five years compared to the entire period (1979-2016). See Figure 3 below.

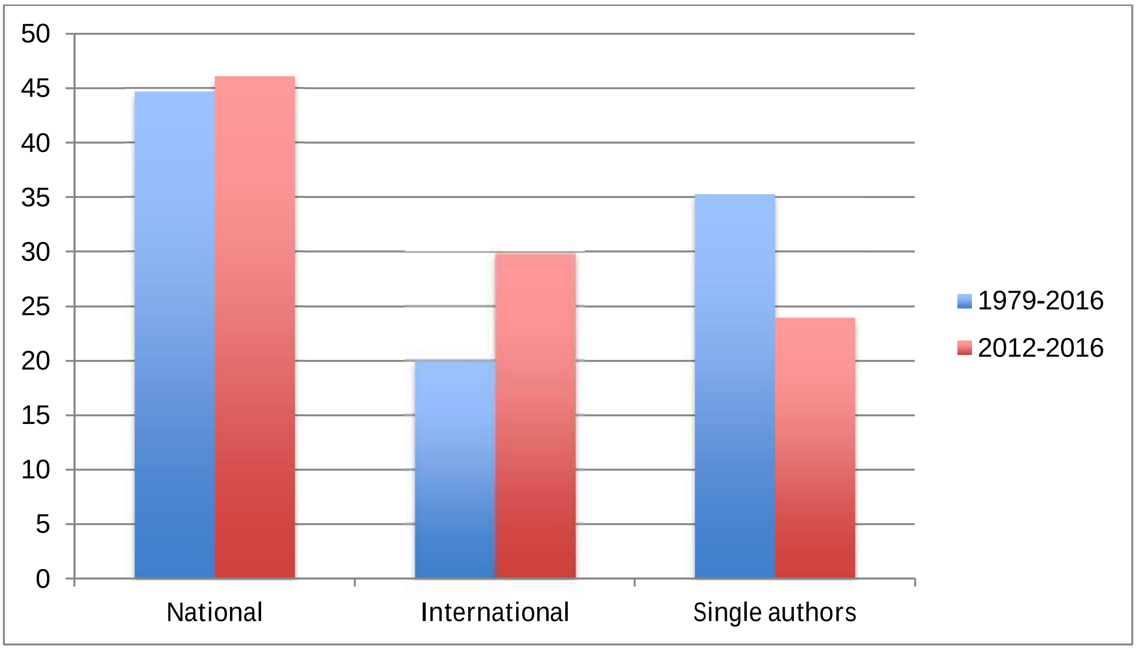

Figure 3: The percentage of papers with authors collaborating nationally and internationally on research studies and systematic review papers published in the three journals *SCX, PUS, and JCOM.*

3.2 Which authors are most likely to collaborate?

Authors in the most productive countries – the USA and the UK – are not the most likely to collaborate. An analysis across the top eight producing countries for the three specialist science communication journals shows the USA has a very low rate of international collaboration. Germany and Australia are the most collaborative (see Figure 4).

The USA and the UK are more likely to publish papers with single authors or with authors collaborating internally; and most research studies and systematic reviews produced by Italy are by single authors.

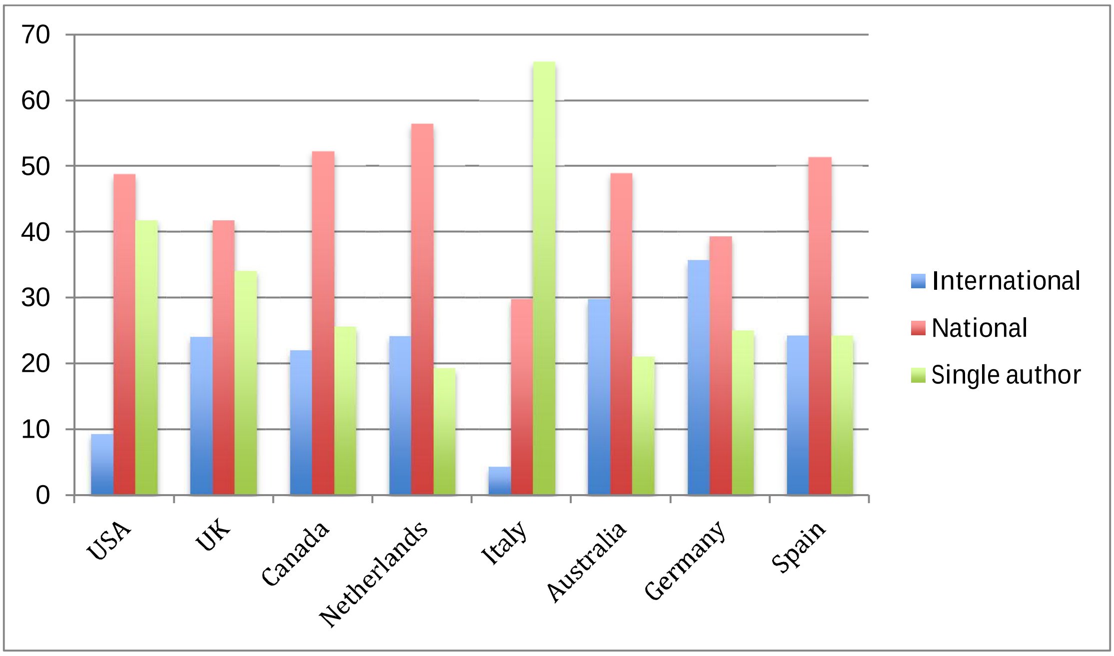

Figure 4: 1979-2016. The three specialist journals: the percentage of research studies and systematic review papers with authors collaborating for the top producing countries: USA (n=531), UK (n=196); Canada (n=75); Netherlands (n=55), Italy (n=47), Australia (n=47), Germany (n=43), Spain (n=32)

In the past five years all eight countries have increased their international collaboration, for example: USA (9% to 15%); UK (24% to 35%); and Italy (4% to 12%). The level of single authorship has decreased correspondingly. Most countries (bar the UK, Canada and Spain) have also increased levels of national collaboration.

3.3 Single authors mostly publish in the general journals

An examination of all the papers published in *Nature* and *Science* journals as well as *Scientific American* where the authors' countries could be identified (n=116) showed most were written by single authors (62%). Where collaborative work was involved, international collaborations out-numbered national collaborations by two to one: 26% to 13%. More prolific authors from the USA and the UK generally undertook both types of collaboration. Even so, most papers by American (75%) and British (71%) authors were single author. An examination of the systematic reviews shows more international (51%) and national (20%) collaboration and far fewer single authored papers (29%). Over time, national collaboration has increased and single authors have decreased.

3.4 Digitisation and funding incentives driving international collaboration

Most experts were interested but unsurprised to hear of the recent increase in international collaboration in the specialist journals: "This was not surprising to me; the fact that conferences are being held international and the global scope of technological developments and science issues – you see this on the issue of climate change and papers published"

(Prof. Edna Einsiedel, University of Calgary). Some said that similar increases were also found in research published in other disciplines. The reasons they offered were:

- Major American and European funding for large collaborative multi-country and organisation research projects: "Many granting agencies require participation by social scientists in large-scale projects so there have been more publications on science communication-related questions" (Prof. Edna Einsiedel, University of Calgary). In Europe for instance, this phenomenon can probably be attributed to the European policy of "Responsible Research and Innovation" (RRI).
- Institutions pushing researchers to collaborate through mechanisms such as increased academic rewards for multi-authored papers
- The internet making collaboration easier
- The influence of international events such as the Public Communication of Science & Technology (PCST) biennial conferences
- Direct efforts by journal editors (especially PUS and JCOM) to support collaboration

4. Research Mainly Without Disciplinary Focus

4.1 Most SCR publications address "science" in general

More than a third (36%) of the research studies and systematic review papers published in the specialist journals in the period 1979-2016 fell into category of 'general science', meaning they did not address science communication in relation to a particular scientific discipline. While this is not a negative outcome, it does mean there are fewer studies focused on the specific issues facing various disciplines. When papers were based on a disciplinary context, it was most likely to be biology (including medicine / health) at 24%. This was followed by environment / ecology (14%), technology (13%), and social sciences (6%). All other disciplines were covered by fewer than 4% of the papers (see Figure 5).

Analysis of the same types of papers (n=60) in the general journals and *Major Works* produced similar results. Most had no disciplinary context (48%); but where such a context was present, biology (25%) ranked top from technology (12%), physical sciences (7%), humanities (5%) and environment / ecology (3%).

In total, between 1979 and 2016, the three science communication specialist journals published 1,350 papers in the categories of research studies (1,083) or systematic reviews (267). Between 1903 and 2016, the three general publications included 26 systematic review papers and no research study papers. The *Major Works* included 14 research study papers and 20 systematic reviews. Coders could select one major disciplinary context for each paper (e.g. biology), and then up to three more specific disciplinary contexts for each paper, which were linked to the major discipline chosen for that paper (e.g. medicine/health, genetics).

4.2 Recent shift to papers with a specific disciplinary context

An analysis of specialist journals shows a recent (2012-2016) trend by authors to focus their work in a disciplinary context, such as biology (28%) or environment / ecology (22%), as shown in Figure 5. The figures for the physical sciences, mathematics and earth sciences are much lower, as are papers focussed on the humanities, arts and social science.

4.3 Arguments for and against discipline-focus

Most experts interviewed were unsurprised by the prevalence of a biology and environment disciplinary context in the papers. Most thought the increasing focus on specific disciplines in recent years was a positive development, while others were concerned that funding agendas may drive this, and therefore putting 'big picture' science communication at risk. One expert said: "Research often depends on availability of money, which is related to problems that politicians perceive as problems – such as climate change, nuclear power, and now embryonic research and reproduction research" (Prof. Hans-Peter Peters, Forschungszentrum Jülich).

Several experts saw the lack of a specific disciplinary context as an important gap in science communication research. They postulated it could lead to a lack of focus on concepts and ideas, both important for the theoretical development of science communication.

Another view concerned the lower (and declining) publication of science communication papers about technology, which several experts considered was caused by a diversion of papers into more specific journals; or as Edna Eisendel put it, from science communication journals into journals covering "biotechnology, human genomics, nanotechnology, and more recently synthetic human biology."

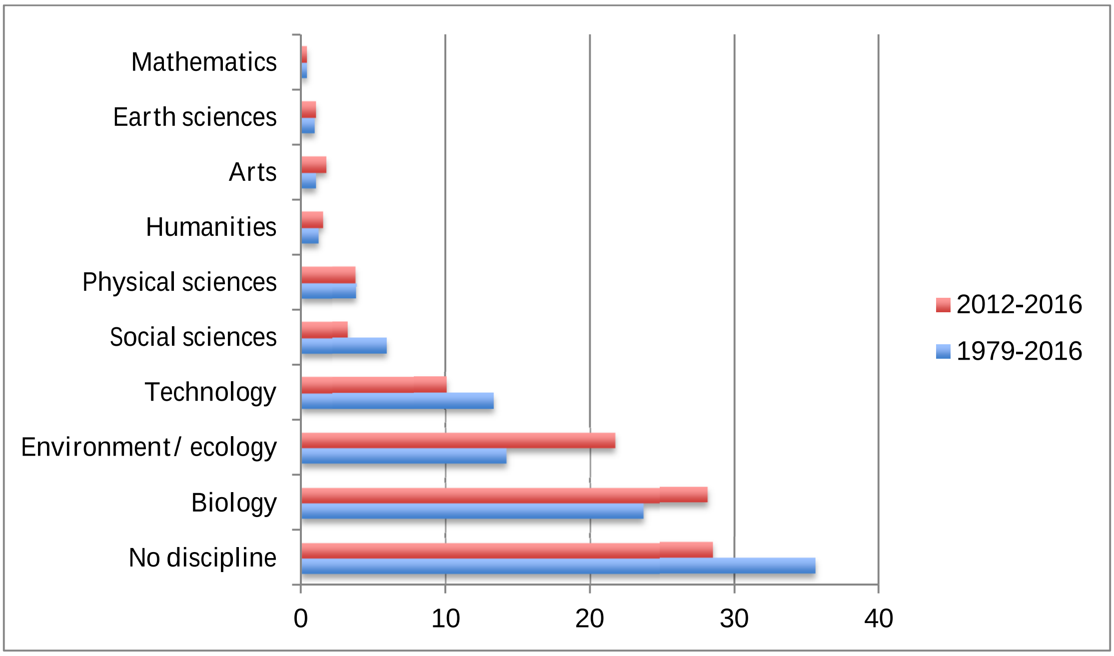

Figure 5: Percentage of research studies and systematic studies focussing on different disciplines.
N.B. This report uses "no discipline" from the coding scheme interchangeably with "general science" as the experts discuss and often call it.

4.4 Comparing the disciplinary context with the topic

Analysis of the research studies and systematic reviews in the three specialist journals found:

- Media / social media topics cover all disciplines except physical sciences.
- Science communication theory topics dominate papers with no disciplinary context, as well as the most frequent contexts of biological sciences, environment/ecology and technology.
- Topics covering 'publics' and 'education and training' were most often found in papers focused on humanities and social science disciplines.

Research with a disciplinary focus on the Arts, was more likely to study *objects* (e.g. newspaper articles, blogs, texts, exhibitions) than *people*. For all disciplinary contexts (except for social sciences) the public was both the major participant (directly studied by the researcher through surveys, focus groups, etc.) and the major target group (indirectly studied by analysing tools such as newspaper texts, blogs etc., which have a 'target group' in mind). - For research papers focused on a social science context, researchers dominated as both the participants and target groups for research.

4.5 Digging deeper into those broad disciplinary boundaries

Coding of papers published in the three specialist journals for sub-disciplines revealed that biology is dominated by studies about health / medical research (55%) and genetics (24%). Climate change (53%) is the largest group in the environment / ecology context; and papers on biotechnology (49%), and nanotechnology (27%) are leading in the technology context. Other disciplinary contexts have too few papers to produce meaningful figures.

Similar results were found for papers analysed in the general journals and *Major Works*.

The politicisation and contested views of climate change, biotechnology and nanotechnology may well be a reason for seeing many papers focus on these contexts. This backs up the perceptions of the experts, who said that controversial science issues drove the specific contexts for science communication research.

4.6 Comparing approaches by male and female researchers in the specialised journals

A comparison of the disciplinary context with gender found that female corresponding authors publish more research studies and systematic review papers than male authors on specific disciplines such as biology, physical sciences, arts and humanities. They are slightly more likely to publish papers on environment/ecological sciences disciplines, and this trend has increased over the last five years (2012-2016). They write a majority of science communication papers in all biological areas.

By contrast, male authors write more of the research studies and systematic reviews that do not specify a discipline, and also more on technology (except for nanotechnology) and climate change. Female authors have increased their publication rates during the past five years of climate change papers.

5. Main Theoretical Focus

5.1 'Science communication theories' common theme, yet mainly in reference

While 'science communication theories' emerged as the most common topic with 41%, it should be noted the papers coded this way are likely to be *referring* to theories, rather than *developing or exploring* theories about science communication. It should also be noted that the separate major topic of 'engagement' is likely to be also associated with some references to science communication theories. Most papers focused theories from 'public understanding of science' and 'technology' (42%), 'risk communication' (30%) or 'science literacy' (16%). Science communication theory focusing on the public understanding of science or science literacy was equally prominent in the general journals and *Major Works*.

These results support the expert analyses (25/33), which predicted the dominance of research into science literacy and public understanding of science, particularly with earlier science communication research: "Thirty years ago we were talking about science literacy and public understanding of science, and research began in the late 1980s and early 1990s helped to focus us away from science literacy to public engagement and talking about the need to pay attention to what audiences need and what their interests were and what knowledge they already have." (Prof. Bruce Lewenstein, Cornell University)

After seeing initial results from the journal analysis, the experts were concerned that funding priorities may mean that too little attention is given to theoretical studies. One expert asked: "Where is the higher-level conceptual thinking that connects things – is the discipline fragmenting with so many small individual studies? I am becoming more convinced we need research that takes a step out and considers some concepts and issues and not just one off small studies." (Prof. Joan Leach, Australian National University)

Others noted the difficulty of publishing theoretical papers compared to empirical research data. But Susanna Priest, editor of *Science Communication*, said: "We don't publish any paper that is just about theory… and we don't publish any paper that doesn't include theory." The prominence of this topic indicates many research studies and systematic reviews refer to science communication theories, without necessarily examining them in depth.

There is a basic level of interest in communication theory. Massimiano Bucchi, recently appointed editor of *Public Understanding of Science*, said: "Our most cited papers are classical theoretical papers. Brian Trench and I published a paper on 10 key words of science and society[15], and after three days of being posted on Academia there were 600 views. So clearly there is a demand for theoretical papers and modelling".

In analysing this context, coders could select up to three major topics for each paper (e.g. attitudes / behaviour, media / social media, science communication theories) and then could select more specific disciplinary contexts for each paper, which linked the major topics chosen for that paper.

5.2 Media and social media the second most popular topic

Under the broad heading of media, the topics covered in the three science communication journals were print media (33%), science writing / journalism (23%), all mass media (21%), and radio and television (9%). Relatively few covered online media (8%), social media (0.5%) or blogging (1%). The number of publications under this broad heading has not grown significantly in the last five years (37% to 40%).

[15] Bucchi, Massimiano, and Brian Trench. "Science communication and Science in Society: A conceptual Review in ten keywords." *Tecnoscienza (Italian Journal of Science & Technology Studies)* 7.2 (2016): 151-168.

This pattern was replicated in coverage in the general journals and *Major Works*, where mass media, print media, radio / TV and science writing dominated media research.

The experts predicted this popularity of media research, especially in early SCR publications, but the low level of research into online, digital and social media surprised them. One expert called for more research into new media: "How are new media platforms being utilized? How are these platforms changing the way science is communicated?" (Prof. Edna Einsiedel, University of Calgary) In contrast to the journals, the grey literature does focus on these areas, looking at how digitalisation and social media are becoming more important to science communication.

5.3 Attitudes and behaviours: the third topic

One third of research studies and systematic review papers published in the specialist journals examined attitudes and behaviours, and that proportion has risen to 40% in the last five years. Most (86%) were about beliefs, perceptions and values, with 8% focused on behavioural change. Attitudes and behaviours were also significant topics in *Major Works*, but not in the general journals.

5.4 Tools, methods and practices: the fourth topic

Most papers about science communication tools, methods or practices were on visualisation / images (18%), specific tools (12%), museums / science centres (12%), or science and art (7%), but a large proportion (24%) were coded as 'other' due to focussing on very specific methods and practices. Only 5% of the papers looked at 'open science'[16] as a method, and even fewer (2%) examined 'public relations' as a method.

5.5. Other topics in the specialist journals

Figure 6 shows there were relatively few research studies or systematic reviews in the specialist journals on other topics such as engagement, education / training, science communication actors, publics, and history of science communication. In contrast, papers published in general journals did cover science communication actors, focusing mainly on scientists.

[16] Open Science as a coded research topic within the cluster "science communication" refers to analyses of policies and practices to open up the scholarly publishing system towards open access, and open data.

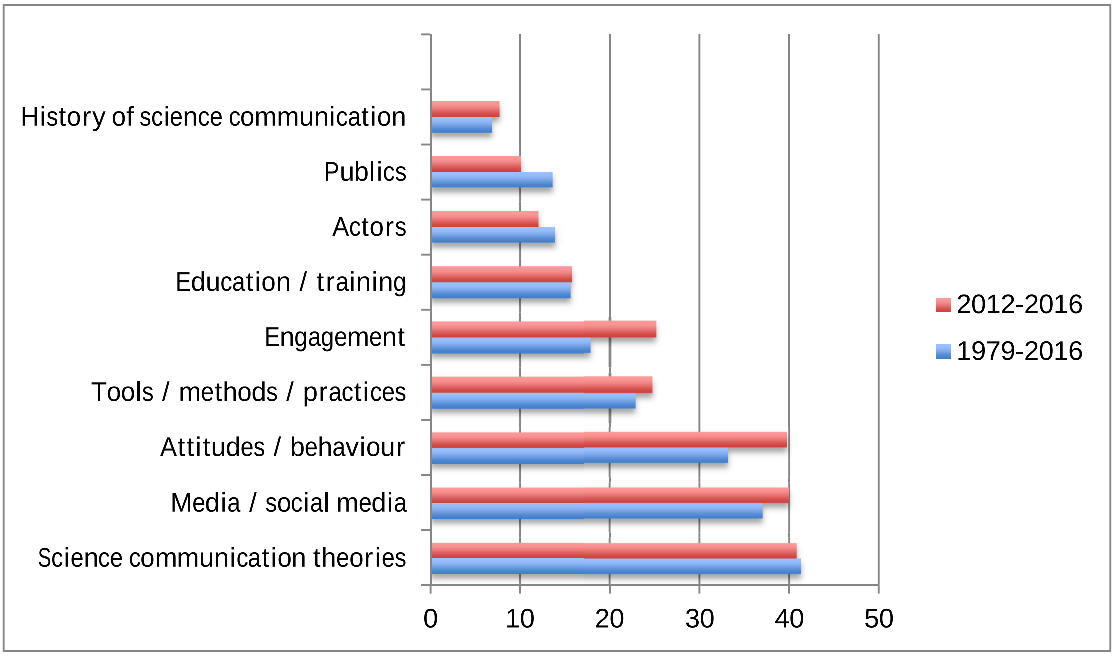

Figure 6: Percentage of research studies and systematic reviews in the three the specialist journals, focussing on different major topics. (Each paper could include up to three different topics.)

5.6 Research into 'upstream engagement' increasing

While coming off a relatively low base, the number of papers on engagement has increased over the past five years. The experts thought this should be a popular topic as the term is now in common use, but there appears to be a time lag between the use of the term 'science engagement' and its presence as a significant topic for research or systematic review.

At the suggestion of some experts, engagement topics 'participation' and 'public engagement' were compared with the topic 'public understanding of science' (listed under the major topic of 'science communication theories') for the full research period. 'public understanding of science' was the dominant topic until 2010 but has since declined, to the point in 2016 where papers on 'engagement' (30) were double those on 'public understanding of science '(14).

The grey literature devotes even more attention to 'public engagement' than the specialist and general journals, through surveys, which map activities and theoretical discussions about public engagement as a spectrum of activities. Just like in the journals, this focus on "engagement" is contrasted to deficit and dialogue models, i.e. looks more at including stakeholders, co-creating research, and learning from groups formerly reduced to 'audiences'.

Experts considered public controversies about science (e.g. mad cow disease / BSE, nuclear power and genetic modification) to drive policy makers and institutions to look at different and more effective forms of science communication, including dialogue and participation. "There has been considerable research on new / emerging technologies which began some decades ago with the focus on biotechnology. The ensuing controversies around this technology were fodder for more science communication research." (Prof. Edna Einsiedel, University of Calgary)

Experts also believed the growth and institutionalisation of science communication practice (especially over the last 20 years) has changed the nature of science communication research.

However, one expert was concerned about the increasing focus on engagement and a research community potentially overestimating its capacity to explain this in theory: "The conceptualisation of engagement is idealistic and follows the idea of an ideal speech – some of the social theorists imagine this as a genuine practice. They assume it is possible for us to be ideal in engagement… but few studies point to engagement being ideal in practice – so if we can't get it right in practice why do we think we can theorise." (Prof. Richard Holliman, Open University UK) The grey literature records many references to a shift from 'public understanding of science' to 'public engagement with science', with 'engagement' moving upstream to determine the direction of research. It also examines the idea of 'expertise' and the role of scientists and science within society, particularly within the context of having a social license to operate and providing rewards for science communication activities. The grey literature demonstrates a growing contextualisation of the science, making the case for a reward system that recognises contributions other than publication in journals.

6. Research Mostly Studies the 'General Public'

Each SCR publication was analysed as to which extent it focuses on social settings / people (e.g. their attitudes / behaviours), and / or objects (e.g. newspaper texts or online blogs). For each research paper, the coders could also select up to three different participant groups where researchers had focused on studying attitudes and behaviour, and up to three different target groups for where researchers had focused on objects.

6.1 More studies focused on people than communication formats and channels

Most of the research studies published in the specialist journals over the full study period focused on people (52%) than objects (34%) or a combination of people and objects (14%).

These figures surprised some of the experts, who expected more researchers to include both people and objects: "It is surprising that not more research on using both people and objects – such as content analysis of texts and then checking what this means with people." (Assoc. Prof. Ayelet Baram-Tsabari, Technion). Of the 14 research studies included in the *Major Works*, nine were focused on objects, four on people and one on both.

6.2 Comparing people and object-based research

People-focussed research was mostly about science communication theories (30%), attitudes / behaviour (26%) and engagement (14%).

Object-focussed research papers were most frequently on media / social media topics (31%), science communication theories (16%) and attitudes / behaviour (8%). The three most common topics covered by research studies covering both people and objects were attitudes / behaviour, media / social media, and science communication theories.

Comparing participants or target groups with other variables coded showed that:

- When research studies the general public, statistical rather than content analysis is used to assess the data, which likely reflects the high use of questionnaires / surveys as a research method
- When technology is the context for research, the participants or the target groups are most likely to be scientists / researchers, and the topic is most likely to be 'science communication actors'
- When research involves participants other than the general public, interviews, observations and focus groups are more likely to be used than questionnaires.

6.3 Researchers mostly studied the general public rather than more specific groups

When looking at the participants in the research studies published in the three science communication journals where coders could choose up to three different participant groups, the most common group to study in research studies published in the three specialist journals was the general-public / citizens (31%), followed by scientists / researchers (19%). No other group featured in more than 8% of papers, and studies involving indigenous communities (0.5%), artists (0.3%) or senior citizens (0.2%) were extremely rare. These percentages have not changed significantly in the past five years.

In gender analysis, female corresponding authors showed a much stronger interest in studying people, with 53% looking at 'the general-public / citizens'. This contrasts with a preference by their male counterparts (55%) to have no participants in their research (in other words, to be studying objects like a media item).

Research studies investigating people most commonly use questionnaires / surveys (33%), interviews (17%) and focus groups (7%). Statistical analysis of data (31%) is used more than content analysis (22%) for these studies.

6.4 Researchers mostly study objects whose target group is the general public

The analysis was then applied to 'target groups' (defined as the people interested in or affected by an object under study; for example, if a media article was analysed, the 'target group' is the audience the article is aimed at). For most of the research papers in the specialist journals, the most common target group of the objects studied was again the 'general public / citizens' (48%), followed by researchers (23%), stakeholders (15%), government administrators / policy makers (7%), media professionals (5%) and business / industry / commercial interests (4%). All other target groups were mentioned in less than 3% of papers. Only one study focused on objects targeting senior citizens. In the last five years there has been an increased number of research studies targeting the general public (55%), researchers (27%) and stakeholders (23%). This means objects with other target groups have been studied even less in the last five years. Research studies investigating objects mostly used content analysis (25%) to assess the collected data rather than statistical analysis (14%).

A comparison of genders showed female corresponding authors are more likely to have no target groups (52%) in their research, likely because they researched people rather than objects. Male authors were more likely to be studying objects where the target group was general-public / citizens (52%).

The participants and target groups of the 14 *Major Works* research studies followed a similar pattern, dominated by studies involving or targeting the 'general-public / citizens'.

6.5 Increasing attention by researchers to stakeholders

'Stakeholder' is a term increasingly used in research studies, both as 'participants' (where their behaviours are studied directly) and as 'target groups' (for instance, where a website or media report aimed at stakeholders is studied). This corresponds to the increasing use of this term in English since the mid-1990s. Stakeholder Theory owes much to the U.S. scholar R. Edward Freeman in the 1980s. Basically, a stakeholder can affect or be affected by the activities of an organisation.

7. One-off Research Studies Mostly Use Questionnaires

All SCR publications were coded as to whether they were a one-off-study, longitudinal or pre/post experimental in nature. For each research paper, coders could also select up to three different research methods and three different data analysis techniques.

7.1 Most research is one-off assessment with declining longitudinal and pre/post studies

Most of the research studies (93%) published in the three journals are one-off assessments. Pre/post-experimental studies (4%) and longitudinal studies (3%) extending over 10 years or more are very rare, with only 75 such studies published over a 37-year period.

The proportions have changed little in the last five years, except that the number of longitudinal studies has even declined slightly and pre/post experimental studies have increased. Of 14 research studies identified in *Major Works*, twelve are one-off assessments and two are longitudinal studies.

When longitudinal studies do occur, they are more likely to focus on objects (e.g. newspaper articles on climate change) than people. Pre/post experimental studies mostly investigate people.

The experts were concerned about the low number and continuing decline of longitudinal and pre/post-experimental studies. They saw a reason for this in the lack of funding or institutional support for such studies, and said it was easier to win research grants for single-issue studies. “Longitudinal studies – are difficult to conduct and difficult to get funded.” (Dr. Emma Weitkamp, Editor of JCOM) Also PhD projects tend to focus on a comparatively short time span.

At the suggestion of the experts, the 36 longitudinal studies were compared in more detail. More than half were long-term media studies, typically about print coverage. For example: ‘A Longitudinal Study of the New York Times Science Times Section’[17]; ‘Key trends in environmental advertising across 30 years in National Geographic magazine’[18]; and ‘The uncertainties of climate change in Spanish daily newspapers: content analysis of press coverage from 2000 to 2010’[19].

One quarter of the longitudinal studies focused on beliefs, perceptions or values. Two examples: ‘Attitudes to genetically modified food over time: How trust in organizations and the media cycle predict support’[20]; and ‘The development of young American adults’ attitudes about risks associated with nuclear power’[21].

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[17] Clark, Fiona, and Deborah L. Illman. "A longitudinal study of the New York Times Science Times section." *Science Communication* 27.4 (2006): 496-513.

[18] Ahern, Lee, Denise Sevick Bortree, and Alexandra Nutter Smith. "Key trends in environmental advertising across 30 years in National Geographic magazine." *Public Understanding of Science* 22.4 (2013): 479-494.

[19] Lopera, Emilia, and Carolina Moreno. "The uncertainties of climate change in Spanish daily newspapers: content analysis of press coverage from 2000 to 2010." *JCOM* 1 (2014): A02.

[20] Marques, Mathew D., Christine R. Critchley, and Jarrod Walshe. "Attitudes to genetically modified food over time: How trust in organizations and the media cycle predict support." *Public Understanding of Science* 24.5 (2015): 601-618.

[21] Pifer, Linda K. "The development of young American adults' attitudes about the risks associated with nuclear power." *Public Understanding of Science* 5.2 (1996): 135-155.

A gender comparison shows that male corresponding authors are more likely to publish longitudinal studies (61%), and that during the past five years (2012-2016) female authors are more likely to publish pre/post experimental studies (72%).

7.2 Questionnaires / surveys dominate research methods

Research studies across the three science communication journals were most frequently carried out by using questionnaires / surveys (40%). The second most common method (31%) was to collect and analyse data about a set of objects (for example, a series of newspaper articles on climate change).

Figure 7 sets out different methodologies, and compares their popularity over time. There has been little change to overall trends in the past five years, except for a trend towards more observational research and less database work.

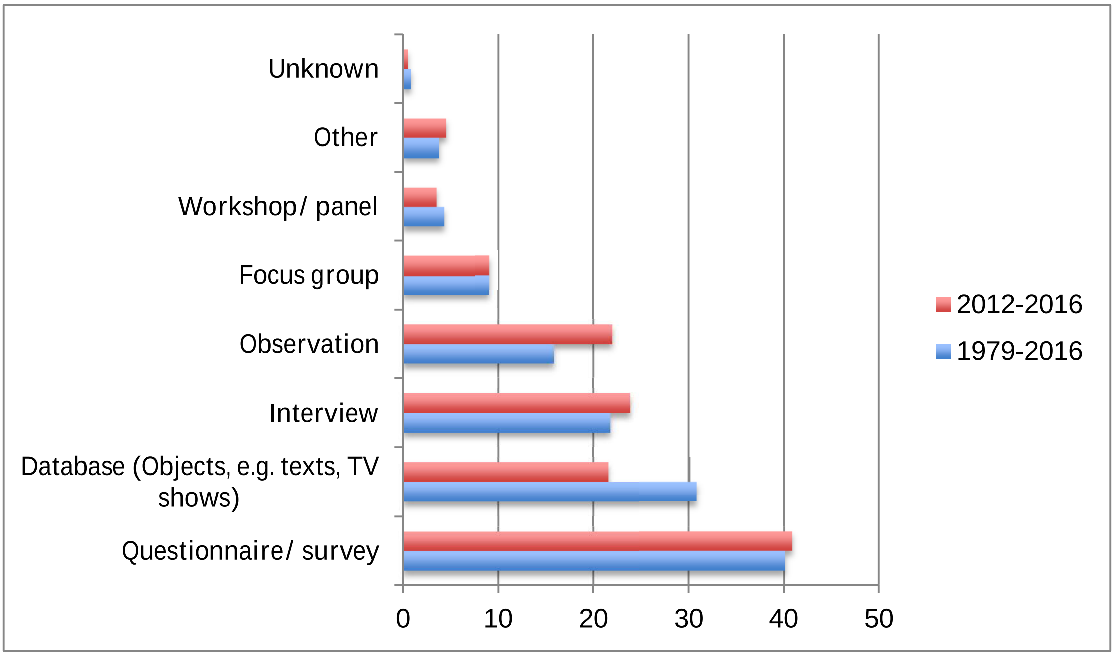

Figure 7: Percentage of each research method used in the research study papers (each research paper could be attributed to up to 3 possible research methods)

The methodologies in the 14 research studies in *Major Works* most commonly used a database through analysing objects such as media texts. Then followed questionnaires / surveys, observations, and interviews. The experts thought that early science communication research would be dominated by large quantitative surveys of the public about their understanding or opinions of science. The content analysis largely supports these perceptions. Questionnaires and surveys remain an important tool for science communication research. “I laughed when I saw surveys are still dominant; survey research from the 80s is still prevalent; everyone runs big surveys.” (Dr. Emily Dawson, University College London)

An examination of papers by the gender of their author reveals distinct preferences in methodology. Female authors are more likely to publish research papers using focus groups (62%), workshop or panel (62%) and interviews (52%), often in combination. Male authors prefer databases (53%) and questionnaires and surveys (50%). However, the last five years has seen a trend for females to use questionnaires and surveys (55%) and databases (53%).

When ‘research method’ was compared with ‘topic’ for the same papers, the following patterns emerged:

- Researchers studying ‘engagement’ are most likely to use interviews or workshops / panels as a research method
- Researchers studying ‘media / social media’ are more likely to assess databases than investigate people (except through observations)
- Researchers studying ‘attitudes and behaviours’ or ‘science communication theories’ will use a combination of methods.

7.3 Content and statistical analyses dominate

Given the high use of surveys and questionnaires and secondary data (databases) by authors publishing research studies, it is not surprising that data are mostly assessed through content analysis (57%) or statistical (51%) analysis. Surveys and questionnaires are mostly statistically analysed, while other research methods generally use content analysis.

Discourse (12%) and rhetorical (5%) analysis is far less likely to be used to assess the data. An examination of papers published over the last five years shows no significant variation.

Historically, male authors use more statistical analysis (54%) than females, but in the last five years female authors have caught up and overtaken male authors in using statistical analysis (51%). Female authors use all other data analysis techniques more commonly than males.

The 14 research papers included in *Major Works* used only statistical and content analysis methods, in that order.

7.4 Experts on quantitative and qualitative methods

The experts were divided over the implications of different approaches to science communication research. They noted the increasing mix of quantitative and qualitative methods used by researchers, and some saw this as a sign that science communication was growing as a distinct field of academic research. One expert noted: “When I wrote my own thesis I hinted at the unfertile isolation of quantitative and qualitative studies and the positioning between these. I think this has levelled off in some way.” (Dr. Niels Mejlgaard, Aarhus University)

Others were concerned at the continuing bifurcation into quantitative or qualitative methodologies. They felt that despite the rhetoric, science communication research has remained static, using the same methods and reinventing the same topics. “I don’t see much innovation in methodologies – it’s either quantitative or qualitative work but nothing looked striking unusual or different; this is reflective of the field in general.” (Prof. Edna Einsiedel, University of Calgary) The bibliometric and content analysis data supports these perceptions.

8. Making Research Relevant to Practitioners

The journal analysis did not specifically examine where papers explicitly or implicitly linked research to practice, but this idea was addressed by the experts in the second round of interviews.

It is apparent from the analysis that significant science communication research is being published outside of the three specialist journals or not even published at all due to the lack of impact on practice or even just visibility in scholarship (none of the journals in the field reaches even a Journal Impact Factor at least of 2.0[22]). Furthermore, results from certain more specialised (sub-)disciplines such as Risk Communication or Public Health[23] are often covered in even less visible journals, which increases the fragmentation of the field further. The limited visibility of most results in the field is obviously further obstructed by the fact that most publications are still closed access, which keeps content behind paywalls and thus even technically unavailable for many practitioners. However, even if more research results were publicly available (which they are for instance in the open access journal JCOM Journal of Science Communication), practitioners worldwide are mostly not willing or interested in taking the initiative to work their way through SCR publications. Several non-representative surveys in the UK and the USA have shown this for quite a while. For Germany in particular, a sister project to this study[24] included a highly representative randomised survey, which showed that hardly any practitioners know (let alone use) scholarly journals, and consequently are rarely aware of specific theoretical or methodological schools of thought.

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[22] This means that on average, an SCR journal paper is cited about once a year (twice every two years). The Impact Factor of the more general *Journal of Communication* for instance, published by Wiley-Blackwell, is at least twice as high, 3.9

[23] There is no scholarly consensus among learned societies as to whether these should be considered ’sub-disciplines’ (as for instance PCST argues) or whether “Science Communication” generally is an umbrella term spanning across research areas such as “Organisational Communication”, “Journalism”, “Health Communication”, “Environmental Communication” (as in the working-group structure of the International Communication Association, ICA). There are even organisations such as the International Association for Media and Communication Research (IAMCR) which combine “Environment, Science & Risk Communication”, on eye-level, in one group. pcst.co | icahdq.org | iamcr.org

[24] Gerber, A. et al. (2018). Trendbarometer Wissenschaftskommunikation. Contract research for the German Ministry of Education and Research

8.1 Linking research to practice

Expert's views were mixed about the need to link research with practice. Some considered this an important challenge for all researchers: "We need an applied footprint otherwise we are irrelevant" (Prof. Dietram Scheufele, University of Wisconsin Madison). Others disagreed, saying it was not their role and in any case, not all research in science communication had practical implications: "My job is to look at what is happening and think of that in a deeper and more insightful way. It's not necessarily to make museum practitioners more engaging when they lose all their funding." (Dr. Emily Dawson, University College London)

A few experts felt that science communication researchers were already doing a good job of linking research with practice: "We try and have as many articles as possible to link theory with practice; we are very proud of this." (Prof. Susanna Priest, Editor of the journal *Science Communication*, SCX)

8.2 Two camps – researchers vs. practitioners?

The experts perceived a number of barriers between science communication researchers and practitioners. The cultures of researchers and practitioners are different, and this creates a tension "between two camps". As one expert said: "If you have discussions at conferences then these two groups speak different languages and have different interests."
(Dr. Birte Fähnrich, BBAW / Zeppelin University)

Culture of researchers

- Journals are written for an academic audience and are not always easily understood by practitioners. As one expert said: "The stuff we have the most difficulty publishing is stuff with a practical focus, compared to something that has a theory that is recognised." (Prof. Dietram Scheufele, University of Wisconsin Madison)
- The incentive structure of universities and research institutions favours academic publications, over promoting practice change or evaluation of practice.
- Researchers aim to meet the needs of the group (funders, colleagues) that will judge, employ and promote them rather than solve practical problems.

Culture of practitioners

- Practitioners tend not to read journals or seek out research to inform their practice.
- They feel research has done little to solve practical problems (e.g. evaluation, helping them to mount persuasive arguments to policy-makers).
- Science communication as a field of research expertise is still not perceived to be valuable by practitioners, including policy makers: "We don't have a calling card for

science communication. We can be happy with our tacit communities but if we want to influence policy makers we need to open the dialogue and build awareness of a field of scholarship developed over many years versus a group of individuals with our own contacts" (Prof. Alan Irwin, Copenhagen Business School).

- As editorials and numerous review articles over time have shown, scholars still consider much of science communication practice to be under a 'deficit model' paradigm (providing information for a more or less uninformed or ignorant audience).

8.3 Better linking of science communication research with practice

Experts had three suggestions:

a. Publications

One third of the experts thought summarising relevant research papers in a simpler language and contextualising in practice would be useful. These could be attached to publications or abstracts and provided online, or distributed and promoted through social media. One expert suggested a separate publication: "Practitioners are not really reading journals so there is a room for an applied magazine where articles are published in a style that appeals to non-academics." (Dr. Susanna Priest, Editor of SCX)

The Editor of PUS, Massimiano Bucchi said: "The PUS blog and social media is working quite well. It takes news and comments from practitioners, and can include e-views of books or cinema festivals. Exploiting social media makes it more available to people outside academia and we are receiving positive feedback."

An even more significant challenge, however, would be to transfer not only results from individual studies, but rather integrate different results in systematic reviews explicitly targeted at certain practitioner communities. Such meta analyses are expected to address concrete challenges apparent in science communication practice and comparatively assess the quality of studies for this particular topic / challenge.

b. Interactions

About a quarter of the experts believed researchers and practitioners would benefit from regular conversations, either at occasions such as PCST Network conferences, or even at specific international 'forums of best practice'.

"PCST is great as it gets people to drop their defences and usual barriers" (Prof. Alan Irwin, Copenhagen Business School). Another expert recalled the structure of the 2004 Barcelona PCST conference: "for every paper there was someone from the other side commenting; a practitioner commenting on a research paper and vice versa. We need more of this feedback" (Toss Gascoigne, Public Communication of Science and Technology Network, PCST).

On a national level, such conferences for both practitioners and scholars are rare, such as “Science in Public” in the UK, or conferences by the Latin American Science Communication Association “redPop”. The annual German science communication forum “Forum Wissenschaftskommunikation” increasingly started to include single research contributions in the past few years, mostly by international scholars, yet it would be impudent to say that FWK is already a conference to match-make scholarship and practice. For recommendations of how to develop this potential further, please see below.

c. Involving practitioners

One quarter of the experts explicitly recommended to find out what information practitioners want or need to inform their practice; and that getting practitioners directly involved in the research would help bridge the divide. “Design research and communication together so we have a professional learning community” (Dr. Maarten van der Sanden, TU Delft).

“We have plenty of contributors willing to talk the talk. We need academics and practitioners willing to walk the walk. The engagement needs to start upstream and continue throughout the process” (Prof. Rick Holliman, Open University UK).

d. Other suggestions

Individual Experts had other suggestions:

- Use existing bloggers or commentators to explain the research
- Incorporate research outcomes into science communication training courses and degree programs
- Learn from other communities, such as education research and teaching with their long history of linking research with practice
- Explore how citizen science initiatives are dissolving the boundary between research and practice: “Citizen science is one of the areas where the boundaries of science communication research and practice are getting more diffuse and dissolving because people in that world are trying to ask questions about motivation, recruitment and outcomes to improve their practice.” (Prof. Bruce Lewenstein, Cornell University)
- Produce an online science communication module or ‘MOOC’ dedicated to applying research results and better understanding the evidence-base
- Use case studies to demonstrate the benefits of linking science communication research with practice

Grand Challenges Derived From This Data

The three parts of our study – bibliometric and content analysis of journals, the review of grey literature, and the interviews with experts – have identified the following challenges and opportunities for science communication research.

Need for more longitudinal studies

Many papers on science communication are one-off studies, unconnected to a broader discourse and doing little to advance science communication as a field of study. Most are small isolated research studies or case studies studying just people or just objects.

Science communication needs more longitudinal or experimental pre/post research studies. To some experts, longitudinal studies are a sign of the field maturing: “One thing that shows we are a young discipline are the low numbers of longitudinal studies; as a discipline matures you would expect to see more of these.” (Prof. Lloyd Davis, University of Otago)

Fragmented and changing publication patterns

Four major challenges and gaps were identified:

1. The low numbers and recent decline in publication of systematic reviews, important for recording and framing global developments in science communication research
2. The lack of science communication research papers in the general journals *Nature*, *Science* and *Scientific American*
3. The lag in publishing articles on research into emerging science communication issues in the specialist journals, compared to more immediate publication in the grey literature
4. The fact that science communication research is published across a wide range of journals makes it difficult to identify, assess and build on the full corpus of this research, which again requires more strategic transfer mechanisms

Need for greater analytical innovation

Researchers should be encouraged to broaden the analytical tools from the traditional statistical analysis of questionnaires and surveys, or the content analysis of databases of texts or objects. Options include qualitative methods of interviews, focus groups, and workshops; and applying rhetorical and discourse analysis to such data. Missing are also techniques of big data analysis to gain a better understanding of more complex contexts which cannot be analysed with traditional, intellectual means of e.g. content analysis or focus groups. The grey literature study identified the need for new tools to evaluate and explore public engagement in science.

The experts noted that despite a plurality of disciplines being involved in science communication research, including social sciences, sociology, psychology and communication, there was little research that brought the approaches and methodologies of these disciplines together. One expert asked: “Is science communication a field or a conglomeration of things – that is the question I’d like answered by the research. Is there a field? Is there field theory? Are there field framings? Do we have a discipline here or a subsection of other disciplines?” (Dr. Emily Dawson, University College London)

Research dominated by Public Understanding and media studies

Despite a recent increase in research studies and systematic reviews about engagement, two topics dominate publications in science communication: public understanding of science and science literacy. Other popular topics include traditional media, public attitudes, and specific science communication tools (such as science festivals or exhibitions). Particularly German authors tend to concentrate on researching the traditional media (72% of papers published in the three science communication journals).

Other topics of research are largely absent in the literature. These include social media, behavioural change, education and training, science communication actors, publics, and the history of science communication. The minimal research into publics, science communication actors and behavioural change is very likely constraining the growth in our understanding of the dynamics and processes of science communication practice in different socio-political contexts and cultures.

Disconnect between research and practice

A clear majority of Science Communication scholars considers practitioners to be not willing or interested in looking for research that is relevant for their work. This has been discussed for a long time in various countries and communities. Regarding Germany, there are indicators for this disconnect derived from a representative survey in 2016 among practitioners in Germany, none of whom mentioned any of the three academic SCR journals. Another indicator is the lack of ‘systematic reviews’ to summarise, compare and explain research results in the context of specific practical challenges. Similarly, it is obvious that a better analysis of practitioners’ needs would enrich SCR.
It would be important for both science communication research and practice to establish a form of exchange that goes far beyond academic journals or conferences. An example for this is the global PCST Network, which hosted the world’s first symposium on this form of “Evidence-based Science Communication” (EBSC) in autumn 2017 in Italy, funded by the Rockefeller Foundation. The notion of “EBSC” was developed further in a ‘Manifesto’ published in January 2020 in the refereed journal *Frontiers in Communication*.[25]

[25] Jensen, E. & Gerber, A. (2020). Evidence-Based Science Communication. *Frontiers in Communication.* 4:78. doi: 10.3389/fcomm.2019.00078

Dominance of authors from North America and Europe

Corresponding authors from North America and Europe – and especially the USA and the UK – dominate SCR publications. While authors from other countries appear to be increasing, these are still at very low numbers. Authors from developing nations, especially from Africa, are almost completely missing from published science communication scholarship.

Institutions with a well-established science communication presence (mostly in the USA and the UK) have higher publication rates; and other countries have much lower publication rates because their institutions are either non-existing or only emerging. Considering that there are concrete discussions and even first initiatives to build such structures particularly in BRICS countries (namely in Brazil, Russia, China, and South Africa), there is an opportunity for strengthening international activities at the developing structures in Germany (and possibly beyond) to establish sustainable research hubs.

Corresponding authors from the USA and the UK continue to dominate international and national collaborations. The number of these is increasing, especially so for research studies and systematic reviews, but question marks remain over just how genuine such collaborations are, and further study is warranted.

Half the experts interviewed identified the need for cultural and global perspectives and comparisons stretching beyond the English-speaking world.

Prevalence of male authors, especially corresponding authors

While female authors publishing about science communication has increased significantly in the last five years to 2016, male authors (especially corresponding male authors) still dominate overall science communication publications over the last 30 years.

Rare disciplinary contexts and some life sciences focus

Most science communication research studies and systematic reviews have been written without a specific disciplinary context. Those papers which are contextualised, most frequently fit within biology or environmental sciences, and (to a lesser extent) technology. Few papers cover physical, earth, computer or mathematical sciences; or the humanities, arts and social sciences. Hence SCR covers some parts of the scientific spectrum much more intensive than others. The experts recommended more research into the diversity of specific disciplinary contexts in order to broaden the field as a whole.

Research agenda driven by specific issues and controversies

The propensity of authors to discuss areas of potential controversy (such as health / medicine, genetics, climate change, biotechnology and nanotechnology) skews the science communication story, and means there are significant gaps in research about science communication in less-contested research areas such as astronomy, art or chemistry. Based on the bibliometric analyses in this study, this is particularly true for German research.

Another gap noted by the experts, was research on science as a part of everyday life. They were also concerned how little research there is on the evaluation or impact of science communication practices, including the impacts of science communication on changing the political landscape. Evaluation in practice, according to the experts, is too often limited to a mere monitoring of output, while neglecting the actual question in evaluation, to which extent the outcomes and outflows of certain activities relate to the original policy goals and institutional objectives.

Other experts thought that little attention had been paid to the links between theory and practice of science communication. They criticised both the research for not sufficiently acknowledging challenges and needs in practice, as much as the practice for not sufficiently considering theory and empirical findings from social sciences when making strategic decisions or designing communication campaigns / activities.

Significant publics missing from science communication research

Most of the published SCR focusses on the ‘general-public’ as either participants to be studied directly or as target groups of an activity studied (e.g. a study on a website which has the public as the group it is aiming to inform or influence). Researchers, as science communication actors, come a distant second.

There is very little research on Indigenous groups, artists or senior citizens. Very few papers examine the role of science communication practitioners, an established profession in countries such as the UK, Germany, and Australia, and emerging in many other countries. The absence of research into the practitioner creates a gap in our understanding of the practice of science communication. It also constrains the theoretical development and framing of science communication as an academic field of research.

The English grey literature noted that science communication research rarely examined how the private sector was engaged in science.

Patterns Identified in Previous Studies

Considering that a systematic field analysis of SCR has not been conducted yet before this study, it is inevitably navigating in unchartered terrain. There are at least three publications which have been additionally taken into account as important reference points:

a) Bucchi / Trench's introduction to the collection of *Major Works* (2016a), which then resulted in

b) Bucchi's PUS Editorial (2016c)

c) the U.S. National Academy of Sciences report on "Communicating Science Effectively" (Hall-Jamieson et al. 2016)

All three publications are based on the views of a select group of experts, which in the case of the NASEM report were exclusively U.S.-American. The publications complement and contextualise the empirical research results generated in the Field Analysis. A book which only came out in mid-2017, while this report was being finalised, and hence could not be taken into account any more, is "The Oxford Handbook of the Science of Science Communication" (Hall Jamieson et al., June 2017). In general, the anthology presents a wide spectrum of scientific evidence to make more informed decisions in communication practice. The book, however, is not primarily a reflection on how SCR itself is or should be conducted. The content of the first two Science of Science Communication Symposia in Washington, on which the book is based, had of course been analysed nonetheless for this study.

Another book that should be mentioned, is "Forschungsfeld Wissenschaftskommunikation" (Bonfadelli, 2016), published in German. In a collection of individual contributions, the anthology describes the main theories, methods, and themes in SCR, whilst focussing on the value of research for the development of communication. The book only partly focuses on reflecting needs and gaps of the research field or on making empirically-based recommendations. Markus Rhomberg provides an individual review of potential research perspectives, towards the end of the book. These reflections have also been taken into account whilst developing the recommendations in this study.

The following chapter summarises the key points from the three main publications that specifically analyse and discuss the status quo and future needs for SCR. A matrix compares these reports to our empirical findings.

Patterns and Trends in *Major Works*

In analysing and selecting the most relevant contributions to science communication scholarship in the young history of the field, Bucchi / Trench (2016a) have identified eight developments:

1. The amount of publishing increased
2. Nationalities of publishing researchers are increasingly diverse
3. An increase in joint authorship, possibly due to an institutionalisation of the field
4. Fewer natural scientists and more communication scholars publish science communication research
5. The term “science communication” is meanwhile well-established, compared to a wider variety of competing concepts in earlier times.
6. Gender diversity has increased but is still out of proportion to women’s strong representation in science communication practice
7. The average age of a science communication researcher has been decreasing
8. Most disciplines dealt with in SCR are still from the life sciences

As originally outlined in 2014 by the same authors, Bucchi / Trench, point to five research challenges to be addressed by the scientific community:

- **A.** Increasing fragmentation of actors, publics and media
- **B.** Disintermediatisation (marginalisation or displacement of established intermediaries)
- **C.** Desequentialisation (blurred borders between traditional sequences in the communication process, from specialist discourse to didactic explanation and finally to popularisation)
- **D.** Situating science in culture and thus looking for conceptual affinities and potential inspiration in humanities, arts and culture
- **E.** Expanding the scope of SCR to global dimensions to share experiences and conduct comparative research

“PUS” Research Outlook

In addition to the analyses in *Major Works* (s.a.), Massimiano Bucchi, being the new Editor of Public *Understanding of Science*, dedicated his introductory editorial in 2016 to an outlook on trends and challenges for more evidence-based science communication strategies.

- **A.** Even though paternalistic models of science communication (i.e. those models assuming an inevitably positive effect on people’s attitudes by providing them with more information) have repeatedly been proven invalid by research, the wheel of science communication practice is still being reinvented due to a disconnect with scholarship in this field.

B. The scholarly consensus to move away from conceptualisations of science and society as separate from each other is expected to lead to further investigation and then also practical application of more complex maps of the relations between science and its publics.

C. Due to the digitisation of our media environments, traditional mediators such as legacy media / journalists and museums are increasingly losing their central role as filters and presumed guarantees of the quality of information. This tendency, which has been described as “Disintermediation”[26], requires analyses and solutions for fundamentally new methods and structures of mediation. Just like in other industries such as travel, the loss of intermediaries (e.g. travel agencies) has led to new, collaborative networks of quality assessment and hence new trust relationships. With regard to scientific information, such networks are not yet theoretically conceptualised.

D. Due to increased technical and aesthetic quality of images used in science communication, research should focus more on “visual scientific literacy”.

E. As in the 2009 scandal around “Climategate”, the above-mentioned blurred borders between traditional sequences in the communication process would require more research into how research itself exchanges data and information today.

F. The global spread of science communication practice underlines the need for more comparative research about cultural differences and similarities.

Challenges and Recommendations from the NASEM Report

Based on the contributions by 13 U.S.-American scholars, the National Academy of Sciences report on “Communicating Science Effectively – A Research Agenda” (2016) analyses the following challenges:

1. A better scholarly understanding of how science communication impacts policy
2. Success criteria for formal public engagement, especially citizen participation
3. Communication about controversial topics, i.e. a better understanding of values and trust; means of communicating either consensus or uncertainty; responding to misinformation and framing effects
4. Changing media environments and the behavioural effects of online social networks
5. A systems approach for a more robust understanding of the different contents and channels, communicators and audiences

[26] Gerber, Alexander (2017): “Reinventing Science Journalism in the Age of Disintermediation”. ECJS 2017.

6. Large-scale effectiveness research to compare different approaches, e.g. by means of randomised controlled field experiments; simulation of real-world communication environments; big data research, e.g. in online media
7. More replication and comprehensive / systematic reviews

Based on an analysis of these challenges, the report emphasises four key aspects in developing a more coherent SCR enterprise:

A. Researchers and practitioners need to form partnerships to translate what is learned through research into practice and to develop detailed research agendas for testing hypotheses about how to communicate science that are realistic and pragmatic. Both sides need opportunities for exchange and synthesis of information and ideas.

B. Disciplines that study science communication are similarly disconnected. The field needs new or refocused journals and professional meetings and other forums which would support interdisciplinary and practice-driven research collaborations.

C. Researchers at all career levels may need additional training or be encouraged to work in teams that include partners with the necessary expertise.

D. Mechanisms for rapid review and more timely funding schemes in case certain challenges emerge suddenly such as the Zika virus in 2015/16.

The table overleaf shows that 15 out of the 21 of those trends and recommendations from the three studies have been confirmed or even empirically proven by this Field Analysis. The remaining six issues were obviously also integrated into to the recommendations.

General developments of SCR (as in *Major Works*, mostly confirmed by this study):

Bucchi / Trench (2016)	This Field Analysis (2017)
More ICR output	☑ Bibliometrically confirmed, recommendations accordingly
International diversification	☑ Bibliometrically confirmed, recommendations accordingly
More joint authorship	☑ Bibliometrically confirmed, recommendations accordingly
More of a social science	☑ Confirmed by content analysis & panel, recommendations accordingly
SC established concept	☑ Confirmed by content analysis & panel, recommendations accordingly
Gender diversity	☑ Confirmed by content analysis & panel, recommendations accordingly
Younger researchers	(not measured in this study)
Biologisation	☑ Confirmed by content analysis & panel, recommendations accordingly

Recommendations and suggested topics for SCR in previous research (mostly matching recommendations from this study):

Bucchi / Trench (2016a) & Bucchi (2016c)	NASEM (2016)	This Field Analysis (2017)
Quality issues due to Disintermediatisation	**Changing media environments**	☑ Results comparable, recommendations accordingly
Global dimensions, comparative research	**Systems approach; systematic reviews**	☑ Results comparable, recommendations accordingly
Disconnect to practice leads to reinventing the wheel	**Interconnecting research and practice**	☑ Results comparable, recommendations accordingly
Desequentialisation; changes in scholarly communication		☑ Additionally emphasised in the recommendations
Science in culture; visual literacy; science & arts		☑ Results comparable, commendations accordingly
Fragmentation of actors, publics and media		☑ Results comparable, commendations accordingly
	Policy Impacts of science communication	☑ Additionally emphasised in the recommendations
	Formal forms of public engagement with science	☑ Additionally emphasised in the recommendations
	Large-scale research on effectiveness	☑ Additionally emphasised in the recommendations
	Rapid response mecha-nisms in research	☑ Additionally emphasised in the recommendations
	Controversial topics	☑ Results comparable, recommendations accordingly
	Disconnects within the interdisciplinary field	☑ Results comparable, recommendations accordingly
	Researchers need methods training	☑ Results comparable, recommendations accordingly

Recommendations

The following recommendations are based on the analyses above (i.e. gaps and challenges in SCR) based on the comprehensive bibliometric and content analysis of research literature, a systematic review of grey literature, three rounds of interviews with international experts, and the analysis of previous SCR studies.

A. Research Recommendations

The following summary is ordered according to how relevant certain research needs are according to the experts in this study, and as derived from the other data sources.

1. Topics beyond public understanding, attitudes or media studies
2. Longitudinal and experimental research studies
3. Involve more specific publics and actors
4. Specific disciplines outside the life and environmental sciences
5. Develop theoretical foundations further
6. Encourage a mix of research methods and the use of new tools
7. More ‘horizontal’ Systems Research
8. Foster international collaboration

1. Topics beyond public understanding, attitudes or media studies

Greater encouragement should be given to research that examines topics beyond what has already been analysed extensively (i.e. studies related to public understanding of or attitudes towards science, and science in mass media). Compared to the strong research focus on intermediaries such as journalists and the interfaces with them, SCR experts see much more challenging issues in understanding and responding to the replacement of such intermediaries, and the deconstruction of traditional sequential communication pathways.

Both the experts and previous studies on SCR policies encourage more research into the nexus between science and the changing political and social landscapes. The significance of this area may be additionally highlighted by recent political events including Brexit and the election of Donald Trump, both with their undertones of resistance to social change (which often has a basis in science, for instance industrial automation or climate mitigation) and an increasing distrust in institutions in policy-making and media.

The following neglected research topics emerged from this study as being worthy of closer examination:

- Changing information behaviour and attitude-formation in these digitalised media environments, including the recent debates about ‘post-truth’ and data-driven mass-manipulation; Opportunities, risks and impacts of science communication in interactive media

- Established intermediaries such as legacy media are increasingly losing their relevance for filtering content and exerting some form of quality assurance. As a result of rapidly changing digitalised media systems, these “disintermediated” communication contexts bring about not only new means and tactics but even entirely new actors in communication such as journalistic media platforms which are not ‘journalistically independent’ in a classic sense. SCR could analyse these systemic changes, suggest and experiment with alternative models and practices.

- How to measure and compare the impact of science communication on science and innovation policy and regulation. This should include not merely institutional or journalistic impact but also political influence from organised interests such as pressure groups and lobbyism. Particularly for statutory regulation processes (e.g. regarding the question to which extent CRISPR technology will legally be treated as mere genetic modification) there is a lack of both methods and impact measurement for formal science engagement such as citizen participation processes from an agenda-setting perspective, including community mobilisation and issues of social inclusion. In general, science communication often appears more relevant when topics are more controversial. This study has identified research gaps in understanding the formation of societal values and public trust with regard to science and innovation. Research topics could for instance be communicating either consensus or uncertainty, responding to misinformation and framing effects, etc.

- Communication aspects of the effects which science and technology have or will have on how people live and work, including the tendencies of ‘post-normal science’ (issues where the facts are uncertain, social values in dispute, and yet the stakes particularly high and decisions urgent, e.g. in stem cell research), and the growing social scepticism towards evidence

- Considering that science policy increasingly requests certain forms of communication as part of their funding and / or assessment of research proposals and results, scientific institutions increasingly discuss science communication issues from a governance perspective, both regarding its institutional structures and institutional cultures. This raises the question of how such a communication, which becomes an integral part of academic conduct itself, should be managed and monitored, e.g. regarding incentives and recognition, and how its impact can best be assessed.

- Science in different cultural contexts as part of everyday life

- New / revised theoretical conceptualisations which explain science and society not as separate but as interwoven with each other, leading to more complex relations between science and its stakeholders
- Different approaches for studying public engagement in science and how this is framed. This includes investigations of how publics can help fashion science agendas.

2. Longitudinal studies and experimental field research

More longitudinal studies that examine changes over time would strengthen both science communication practice and research by helping to establish fields in their own right. While longitudinal studies into media and public attitudes are reasonably well established. Other studies needed include topics such as learning journeys of young people throughout their school careers, radicalisation of attitudes and opinions among different cohorts towards science and technology, the changing use of social media whilst growing up, the professionalisation and institutionalisation of science communication and changes in science communication practice over time. Only one quarter of the longitudinal studies focuses on beliefs, perceptions or values.

As shown above, longitudinal studies are not only rare but their number is even decreasing, which is mainly attributed to a lack of specific funding and / or institutional support.

The NASEM Report (2017) additionally advocates strongly for more large-scale effectiveness research to compare different approaches, e.g. by means of randomised controlled field experiments; simulation of real-world communication environments; and big data research, e.g. in online media.

3. Involve more specific publics and actors

Science communication research needs to examine specific groups more closely, breaking down the amorphous ‘general-public’ into more meaningful stakeholders such as marginalised or science-sceptic audiences, groups of people who are simply not at all interested in science, indigenous groups in other parts of the world such as Canada or part of Africa, and in the norther hemisphere also senior citizens. The latter are becoming an increasingly important group given the aging populations of many countries, especially in the developed world.

While significant research is focusing on researchers (or scientists) as science communication actors, more attention needs to be given to other actors involved in the science communication process, especially the science communication practitioners themselves.

4. Specific disciplines outside the life and environmental sciences

As shown in the bibliometric analysis above, biology and ecology have been particularly strong disciplinary focuses in SCR for decades—a trend which has recently even increased. This study therefore recommends encouraging research that looks at specific disciplines outside of biology and environment / ecology. To develop more fully as an academic field, and address the entire spectrum of (not just natural) science and (not just technical) innovation, SCR should also include the contributions of the humanities, arts and social sciences; and physical, earth and mathematical sciences. Topics such as "public history" or "social innovation" are clearly under-researched in SCR.

5. Develop theoretical foundations further

Global and cross-cultural research is particularly relevant for examining and progressing theoretical foundations for science communication research and practice. Such research should:

- Combine the various disciplines involved in science communication with sophisticated mixed-methods approaches, i.e. projects which would probably exceed the scope of regular PhD projects – a priority noted by the experts and also in the grey literature
- Examine geographic, cultural and economic diversity of communicating science and innovation
- Link theory with practice closer so that also the evidence from decades of science communication practice can be integrated in the study design of SCR at large (see also chapter 8 of "Results and Discussion" above, and chapter 1 or the "Policy Recommendations" below).
- Reflect and possibly replicate more past research
- Be large scale and systematic

6. Encourage a mix of research methods and the use of new tools

The experts noted the importance of using a mix of research methods, including those employed in the different disciplines, which contribute to the multi-disciplinary field of science communication. As one expert said: "Then there is the challenge of big data – we have a lot of material available from social media and databases of media content so [we] can analyse large data sets – this requires new methods to deal with this properly as manual methods are not appropriate any more." (Prof. Mike Schaefer, University of Zurich)

Tool-sets which are apparently hardly used in SCR, include data-mining and visualisation software, especially useful for analysing large data sets in areas such as social media. This study leads to questioning whether research grounded in qualitative methods only are a counter-productive consequence of single PhD-driven projects that often omit any use of inferential statistics.

7. More 'horizontal' systems research

Due to the comparatively specific nature of research questions in SCR, often investigating certain effects on certain audiences of certain communication tools about certain topics, the field itself presents itself as rather fragmented. Experts request a systems approach for a more robust understanding of how the different contents and channels, communicators and audiences interrelate. Such projects could probably not be addressed by individual PhD-based studies, which are structurally dominating SCR, particularly in countries such as Germany or the UK. Compared to other disciplines, this can be expected to change once research institutions emerge which provide a critical mass of specialised resources, so that systems research can be conducted across teams and over longer periods of time. This will therefore once again depend on funding mechanisms that encourage inter-institutional and highly interdisciplinary, if not international collaboration.

8. Foster international collaboration

Science communication research in general is lacking collaboration across cultures and continents or even just beyond national borders. Considering that almost all of today's research (as seen in publishing patters of every academic discipline) and a significant amount of practice (considering the large proportion of collaborative consortia projects) are international, just as regulatory requirements and other science and innovation policy measures, more cross-country research would enable the scholarly community to better learn from each other's approaches, avoid mistakes and increase effectiveness.

As much as it appears obvious for European researchers to look primarily for European collaborations, the communities in the Americas or in the Asia-Pacific region often remain among themselves. The experts in this study have therefore recommended including emerging economies and developing countries in collaborations that are not only meant to 'compare' approaches but rather conduct 'comparative' research from the start.

Previous projects, e.g. in the EU-funded SaS / SiS / Swafs[27] programmes, have shown that cooperation between researchers form the northern and southern hemisphere often generates a high degree of mutual learning due to the change of perspectives, e.g. by tackling northern pseudo-science (e.g. counter-productive alternative medical treatments) and superstition (e.g. astrology) by approaches known form integrating indigenous knowledge systems.

[27] Science and Society; Science in Society; Science with and for Society

B. Policy Recommendations

1. Building an SCR corpus with effective transfer mechanisms

If science communication research and practice are to progress, it is therefore necessary to build a freely-available online corpus from a multitude of academic sources (dozens of journals but also grey literature and possibly direct interviews with scholars), so that research is both catalogued for the multidisciplinary SCR community and intuitively explained for different stakeholders such as business, policy-makers, curators at science museums, etc. Such an online platform would need to go beyond repositories such as informalscience.org or news and community sites such as wissenschaftskommunikation.de in Germany. Research results would not just need to be documented and categorised but rather explained or even translated. The goal would be that practitioners can relate to the research by reflecting their work practice, and that they can potentially even test and apply certain strategies and solutions together with scholars. Such a knowledge-transfer platform would have the second important effect that it would allow the social science community to come to new ideas much faster, avoid duplication, and encourage the research field to build on what has already been studied and achieved in the past.

As recommended by a wide range of scholars in this panel study, confirming the analysis of the recent NASEM report, there is a need for much more than merely journalistic reporting about research results. Moreover the experts envisage something similar to what medical sciences have used with great success: systematic reviews. Vice-versa such an initiative should constantly analyse practitioners' needs for SCR, host regular 'matchmaking' symposia, etc.[28]

2. Establish well-resourced science communication research hubs

To ensure more longitudinal and experimental research, it will be important to establish and resource proper science communication research hubs that can act independently. For the time being, such structures are rare exceptions around the word. It should be taken into account how much U.S. players such as NSF, NSME and numerous philanthropical funders have recently strengthened their support for institutions which are already today leading in SCR, e.g. regarding scholarly publications, and now also increasingly for applied and transdisciplinary approaches (see above).

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[28] For the time being, no single research hub in the world, appears to have the resources to supervise such an endeavour sustainably. After discussions about a first outline of such an "Evidence-based Science Communication" platform at the Science&You conference 2015 in France, recently, as a result from the Bellagio conference (see above), institutions signalled their willingness to take the lead. No specific government or foundation, however, has committed yet to funding the initiative. The challenge is that it shall be more than reporting on cherry-picked studies, which is what blogs or newsletters already offer, e.g. the LSE Impact Blog, the ICA and IAMCR news services, or specifically in Germany the "Research" section of the 2016-launched portal site wissenschaftskommunikation.de.

3. Internationalisation and global perspectives

Large multi-national science communication research projects need to be constructed to tackle the urgent issues facing the role of science and innovation in societal grand challenges such as climate change, biodiversity loss, food security or urban living. Such projects would ideally include inter-disciplinary researchers from both developed and developing countries (especially from Africa).

Apart from international private foundations, there are hardly any trans-national funding schemes for SCR on a global scale. The EU framework programme ("Horizon 2020" at the moment) is probably coming closest to encouraging international research collaboration, but even Horizon is limited to the ERA and its non-European matching funds.

Many experts not just in this study but also in previous presentations or publications over the years, have expressed the need for an international taskforce to specifically identify, discuss and develop theoretical frameworks that advance science communication as an academic discipline. None of the learned societies or academies of science have made significant or at least successful efforts to establish a group of experts who together would represent the interdisciplinary and international nature of both challenges and research approaches in science communication. The SwafS Expert Advisory Group of the European Commission maybe comes closest to such an endeavour, although it is just as exclusively European as the recent NASEM expert panel was exclusively American. This is probably why the truly global PCST Symposium on "Evidence-based Science Communication" in November 2017[29] was received with such enthusiasm by the community.

[29] The so-called 'Bellagio Conference' (www.scicom-bellagio.com)

Experts Quoted In This Report

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Prof.	Massimiano	Bucchi	Science and Technology in Society, University of Trento, Italy
	Michel	Claessens	Policy Officer, ITER, International Thermonuclear Experimental Reactor, France
Prof.	Lloyd	Davis	Centre for Science Communication, University of Otago, New Zealand
Assoc. Prof.	Emily	Dawson	Science & Technology Studies, University College London
Prof.	Edna	Einsiedel	Department of Communication and Culture, University of Calgary, Canada
Dr.	Birte	Fähnrich	Academy of Sciences Berlin-Brandenburg; originally interviewed as senior researcher for political communication at Zeppelin University, Germany
	Toss	Gascoigne	Vice President, Public Communication of Science and Technology Network, Australia
Prof.	Richard	Holliman	Chair of Engaged Research, Open University UK
Prof.	Alan	Irwin	Vice President of Entrepreneurship and Innovation, Copenhagen Business School, Denmark
Prof.	Joan	Leach	Director, Centre for the Public Awareness of Science, Australian National University
Prof.	Bruce	Lewenstein	Chair, Science Communication, Cornell University, USA
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