SciPEP
Science Public Engagement Partnership

This work was supported by The Kavli Foundation, as part of the Science Public Engagement Partnership (SciPEP) with the Department of Energy, to advance scholarship on communication and public engagement on basic science. Opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funder. Additional SciPEP resources area available at scipep.org.

The (Very Limited) Evidence Base for Basic-Science-Specific Science Communication in Key Communication Journals

John C. Besley
Department of Advertising and Public Relations
Michigan State University

Karen Peterman
Allison Black-Maier
Karen Peterman Consulting

Jane Robertson Evia
Virginia Polytechnical Institute and State University

August 2021

SUGGESTED CITATION

Besley, J.C., Peterman, K., Black-Maier, A., Robertson Evia, J. (2021) *The (Very Limited) Evidence Base for Basic-Science-Specific Science Communication in Key Communication Journals*. Report for The Kavli Foundation as part of the Science Public Engagement Partnership. DOI: 10.17605/OSF.IO/UECXN

CONTACT

Department of Advertising and Public Relations
College of Communication Arts and Sciences
Michigan State University
East Lansing, MI 48824
517.884.4411 ▪ jbesley@msu.edu

MICHIGAN STATE UNIVERSITY

Contents

Introduction 3
The Project 5
Step 1: Keyword search 5
Step 2. Human Coding to Determine Eligibility 6
Step 3. Human Coding to Determine Data Type 6
Step 4. Qualitative Assessment of Articles with Quantitative, Qualitative, and Case Study Data 8
Discussion 10
Case Study 1: The Evidence Base for Science Communication about Astronomy, Astrophysics, and Space Science 14
Introduction 14
Overview 15
Primary Topics of Study in the Astronomy-Focused Science Communication Literature 16
Conclusion 18
Case Study 2: The Evidence Base for Science Communication about Neuroscience 19
Introduction 19
Overview 19
Primary Topics of Study in the Neuroscience-Focused Science Communication Literature 21
Conclusion 23
Author Information 24
Funding Information 24
References 25

Introduction

This report summarizes sponsored research into the degree to which four key science communication journals have published substantive, data-focused research on communication activities related to basic science. These journals include *Public Understanding of Science*, *Science Communication*, the *Journal of Science Communication*, and the *International Journal of Science Education, Part B: Communication and Public Engagement*. These journals were selected because they represent key peer-reviewed journals where science communication researchers publish. Underlying our research is a desire to give those interested in basic-science-related communication the ability to speak both quantitatively and qualitatively to the degree to which a 'basic science communication research literature' exists within core science communication journals.

The logic underlying the focus on these four journals is that we would expect that any sustained effort to study key challenges associated with communication in the context of basic science would appear—at least partly—in these journals. These journals are also key sites for research and discussion around communication-related topics such as "public engagement."[1] A separate research project by researchers at the University of Wisconsin—Madison simultaneously sought to characterize the broader landscape for science communication research beyond these four journals, and additional short reports have been developed to focus on research in selected basic science areas (e.g., astronomy/ astrophysics/space neuroscience, etc.). The competing hypotheses underlying this research are that:

a) a substantive basic science communication literature exists but that it needs to be foregrounded and mechanisms need to be found to tie disparate pieces together, or
b) that no sustained literature exists.

If option 'a' is supported by the evidence, then the challenge for the basic science community would be how to better coordinate disparate lines of research. If option 'b' is supported, there may be an opportunity to build out a research program that meets the needs of practitioners while providing novel empirical questions for communication researchers. In exploring such questions, the research should also allow for a discussion of the degree to which the current focus of science communication research is too heavily weighted towards questions related to applied science.

By basic science we simply mean research undertaken without an immediate focus on a specific application, including the development of specific technologies. This might be similarly called curiosity driven or fundamental research. Example fields where basic science appears to be common include neuroscience, astrophysics/astronomy, particle physics, chemistry, evolutionary biology, and many others. In contrast, applied science topics might include areas where there is a desire to develop technologies or other tools to solve pressing social problems

[1] For example, a keyword search on Web of Science for "public engagement" and "science" in June 2021 showed that these four journals are four of the top five journals where such content appears. PS ONE was the fourth most frequent user of the combined terms but was excluded here because it lacks specific focus on science communication topics.

such as pollution, disease, or other threats to well-being. We similarly focus broadly on communication research "related to" basic science rather than research on "basic science communication." We do this to reflect the reality that communication research may often focus on outcomes such as self-efficacy beliefs, trustworthiness beliefs, or risk/benefit beliefs related to a basic science topic. In such cases, the research 'is related' to basic science even though it is not specifically about the communication of specific scientific research results. We similarly understand 'science communication' research broadly to include any communication research 'related to' the natural and social sciences and scientists, not just the communication of scientific research.

Nothing in the current research, however, should be taken to mean that science communicators working along the continuum from basic to applied science should ignore evidence about how to communicate effectively … wherever they can get it. A further companion essay to this research summary argues that one way to reframe the challenge of identifying communication research relevant to communicating basic science is to identify the specific behavior-like goals (Besley et al., 2020) that people in basic science areas want to achieve from the efforts and other resources they put into communication.

In this regard, the expectation is that identifying the specific behaviors that we want to affect through communication can enable strategic communicators to look across the social sciences for evidence about what potential communication objectives might drive the desired behaviors (Besley et al., 2018) as well as tactics that might affect those objectives (Besley et al., 2019). Objectives, in this regard, can include scientific knowledge as well as a variety of evaluative beliefs (e.g., trustworthiness beliefs, risk/benefit beliefs, self-efficacy beliefs, etc.), feelings (e.g., interest, joy, disgust, anger, etc.), and framing of topics (e.g., Is this a health issue or an environmental issue?). Further, it should also be recognized that the goal behaviors and objectives that communicators can seek to change should typically include some of their own behaviors, knowledge, beliefs, feelings, and frames. An ethical science communicator, in this regard, should always be eager to consider outside perspectives that might change how they think and feel about their research questions and methods.

The idea that ethical communicators need to make choices that allow them to update what they believe and feel about research-related topics, as well as how they frame such topics, reflects one way to think about the idea of meaningful, two-way 'public engagement.' Public engagement is also addressed in the current research summary inasmuch as the final step in the project provides a qualitative discussion of the degree to which the available literature emphasizes communicating in ways that allow people (including science communicators) to cognitive and emotionally engage in ways that foster the construction of stable evaluative beliefs, feelings, and frames. From this perspective, science communication that primarily focuses on approaches such as using heuristic cues to promote outcomes such as short-term behavior change are inconsistent with a desire for meaningful 'engagement' of science communicators and those with whom they communicate.

The Project

The project proceeded through four stages that we describe in turn. These included an initial generation of keywords that we hoped might help identify research papers focused on basic science (vs. applied science). For step 2, we used human coders to verify that the articles identified were at least somewhat substantively focused on a basic science topic. For step 3, we again used human coders to identify the type of data (if any) included in the paper. For step 4, we provide a qualitative description of the degree to which could provide evidence to help science communicators make evidence-based communication choices. In doing so, we also attempt to understand the degree to which there appears to be consistent overlapping themes and dialogue between the articles

Step 1: Keyword search

Our research team started the project by using Web of Science to download the titles, abstracts, and keywords (when available) for “articles” that appeared in *Public Understanding of Science*, *Science Communication*, the *Journal of Science Communication*, and the *International Journal of Science Education, Part B: Communication and Public Engagement* from their respective startups until December 31, 2020. We excluded content that Web of Science labeled as non-articles, including content labeled “book review[s],” “editorial material,” and “proceedings paper[s].” After downloading, we uploaded the content to the textual analysis software NVivo and generated a list of the most commonly used substantive words. The team and other collaborators used judgement to identify words that seemed likely to help capture either applied or basic research topics. We also consulted the websites of The Kavli Foundation and the Department of Energy’s Office of Science, given their focus on basic science, to ensure keywords related to funder priorities were included.

We provide the final list of keywords that we determined might be especially likely to indicate a potential focus on basic science in the first data column of table 1. As can be seen, of the 2,386 article abstracts/titles we searched, these keywords appeared in 237 articles (i.e., about 10%). Table 2 provides additional words we decided likely indicated a focus on applied research questions (e.g., how to get people to take action on climate change or consider buying genetically modified food). These are much more common. It should be noted, in this regard, that an article could include both basic and applied keywords and would still appear in the list of 237 articles designated as potentially including an emphasis on one or more basic science topics. Articles that included no keywords were also examined to ensure that important keywords related to basic science were not being missed. Many of these articles were about science, in general, rather than any specific topic (e.g., studies related to the Nobel prizes or overall attitudes about science). It should also be noted that the terms “basic science,” “fundamental science,” and “discovery science” generated no meaningful hits.

The most common types of ‘basic science’ keywords were related to astrophysics and astronomy, evolution, and nanoscience/nanotechnology. The “nanotech+” stem was the most common individual term. We debated, however, whether to consider this term an applied-science topic inasmuch as the focus of these articles is, almost by definition, applications of nanoscience (especially perceptions of risk related to nanoscience). We ultimately decided to retain nanotechnology content given the challenge of differentiating it from a focus on nanoscience and these represent about a third (32%) of all initially selected articles.

Step 2. Human Coding to Determine Eligibility

Next, as can also be seen in the second data row of table 1, the first author developed a coding scheme that was then trialed by the additional authors. This simple scheme was aimed at assessing whether the keyword-selected-articles had a substantive focus on a basic-science related topic. After training and refinement using an initial subset of the data, two coders were able to reliably code the content. They then coded the remaining content without knowing what content was being double-coded (Krippendorff's Alpha coefficient for chance adjusted intercoder reliability = .81, n = 24). Disagreements were determined by discussion.

Textbox 1. Coding for Topical Inclusion

Yes/No: Is the article about an identifiable basic science field or fields?

1. Exclude if the article simply mentions a person in that field (e.g., an astronomer or neuroscientist) but is not focused on that field.
2. Exclude if the article appears only tangentially about the field (e.g., it mentions a field as an example but does not specifically focus on that field such as in the case of a study science fiction that mentions a field, but where the study is about fiction, or where the study is a content analysis where a basic science field is mentioned, but where the basic science field is not a specific focus).
3. Do NOT exclude if the article addresses a basic science topic/subject, as well as other non-basic topics such as if a study were to look at nanoscience [a basic science field] and genetic engineering [an applied topic], for example.

The result of step 2 was to bring the number of retained articles to 161, a reduction of 76 articles (and about 7% of the total content). As can be seen in table 2, much of this reduction occurred for articles focused on evolution and physics as several articles used these terms as part of a list of science topics that were not substantially discussed in the actual article. With regard to evolution, many of the exclusions were because the abstract talked about something like "the evolution of" a field. We did not, however, exclude articles focused on topics such as public opinion about evolution even though it could be argued that such articles are not actually focused on the substance of contemporary basic science debates (i.e., they are often really about education in a specific topic area). On the other hand, it seems possible that basic scientists involved in evolution-related research might want to focus their communication efforts in this area and thus we made the decision to retain these articles.

Step 3. Human Coding to Determine Data Type

The third step of our research involved downloading the full text of all 161 retained articles and attempting to determine the type of evidence (or other type of content) that they contained. In doing so, the goal was to identify a subset of articles that contained data that science communication practitioners focused on basic science might use to make evidence-based decisions about how to communicate. We were thus especially interested in identifying quantitative or qualitative data collected to assess research questions or hypotheses about how specific communication choices might affect specific communication outcomes, whether near term objectives or long-term goals (Bennett et al., 2019), as described above. We used the same training and coding strategy used in step 1 but with multiple coding decisions. Again, after training, we were able to obtain acceptable levels of intercoder reliability for the most commonly occurring types of articles post-training (i.e., coders did not know what articles were being double-coded; see table 2 for reliability coefficients).

As table 2 shows, what we found is that slightly more than 1 in 4 of the 161 retained articles provided quantitative evidence from surveys or experiments, whereas slightly less than 1 in 4 provided qualitative evidence from interviews or questionnaires. About a 1 in 5 were content analyses and just more than a 1 in 10 were case studies. The remaining were theoretical or historical discussions.

Textbox 2. Coding for Content Type.

Yes/No: Does the article provide systematic and/or substantive new quantitative evidence from surveys or quantitative experiment? Analyses could include testing of differences between groups using something like chi-square tests or other non-parametric, ANOVA or t-tests, or linear modeling (e.g., correlation, regression). Simple descriptive statistics are not likely adequate. If the evidence is coded from open-ended responses, the focus should be on a quantification of the prevalence of a specific response using a meaningful sample of a specific population; this will typically mean samples above n = 100 and some check of intercoder reliability or coded using automated/algorithmic coding).

Yes/No: Did the article provide systematic and/or substantive qualitative evidence of the results of interviews, surveys or direct observation (i.e., not media content) of contemporaneous events?* In such cases, there is likely to be detailed thematic coding and the sample will typically be a small (n < 50) convenience/theoretical sample and there will be no quantitative intercoder reliability (i.e., Krippendorff's alpha or Cohen's Kappa). Numbers may be provided but these will be likely be used only descriptively). Do not include articles where there may be quotations from interviews or questionnaires but no discussion of systematic analysis.

Yes/No: Does the article provide systematic and/or substantive new evidence from a content analysis of *contemporaneous** news content or other type of publicly available content (e.g., movies, online videos, social media posts, etc.).

Yes/No: Does the article provide a systematic and/or substantive historical analysis of content? The focus should be on a specific set of years that was selected based on specific interest in those years, not because they were the years that most readily available.

Yes/No: Does the article provide a case summary of a recent activity without substantive quantitative data analysis (but not interviews or systematic observation)? This might involve quotations that are not described in a way that suggests they were analyzed systematically.

Yes/No: Does the article focus on providing a theoretical/conceptual/philosophical arguments, including theoretical/conceptual/philosophical critiques of past empirical research without new data?

* Systematic and substantive likely means a discussion of methods/methodological choices as well meaningful reporting of results. Contemporaneous refers to data that is from the specific time period (e.g., last 5-10 years) in which the research was collected and seeks to speak to a still-current issue whereas non-contemporaneous would speak to previous decades/historical era/events.

Step 4. Qualitative Assessment of Articles with Quantitative, Qualitative, and Case Study Data

The final step involved the first author using NVivo software to thematically code the 100 abstracts from articles that step three indicated included quantitative, qualitative, and case study data (note that five articles were coded as including both quantitative and qualitative data). We did so to try to assess if articles were speaking to each other in high-level ways. We did not do a formal cross citation analysis or review of full articles at this stage because our expectation was that we would be able to make a reasonable assessment of the corpus using a less resource intensive approach.

Given the small number of data-driven articles (less than 5% of all articles), it should not be surprising that we saw no clear, sustained focus in the abstracts. In other words, in most cases, it did not appear that the available studies built on each other or sought to answer similar questions in a way that would allow for the accumulation of focused insight.

The most common outcome (or potential outcome) that abstracts seemed to speak to was science knowledge (about 4 in 10 of the articles) and the second most common potential outcome was risk/benefit beliefs (about 3 in 10 of the articles). In some cases, the emphasis was on how events (including discussion-focused events), exhibits, or in-school activities might foster increases in science knowledge or risk- and benefit-related beliefs. In other cases, these variables were included in surveys and the research focused on the correlations between these variables potential communication goals such as public acceptance or support for a science-related policy. Much of this survey research was done in the context of nanotechnology. The only other potential communication outcomes mentioned in more than 1 in 10 articles was some form of emotion (including interest or 'motivation'). Other potential communication outcomes such as audience self-efficacy, beliefs about scientists (i.e., trustworthiness beliefs), and the (re)framing of scientific issues were mentioned only rarely.

Beyond immediate potential outcomes of communication, the only longer-term goal that appeared in the data-driven abstracts reviewed was support (including support for funding) or acceptance for science or a specific technology (e.g., nanotechnology). This type of goal was noted by about 1 in 10 of the 100 abstracts reviewed in step 4. The goal of encouraging young people to consider scientific careers was the next most common and appeared in slightly less than 1 in 10 of the articles. In terms of communication tactics, about 3 in 10 of the articles analyzed seemed to focus on some sort of event or exhibit while about 1 in 10 focused on media content and 1 in 10 focused on the impact of images or art-related activities. It is also noteworthy that about 1 in 10 of the articles focused on the views of scientists using either surveys or interviews. These often seemed to focus on views about how and when to communicate.

Perhaps most importantly, our overall sense in reviewing the basic science-related articles that we identified in step 3 is that there did not appear to be any clear effort by the research to grapple with basic science as a stand-alone concept. More typically, the basic science topic or field was simply (1) a backdrop for an effort to study whether there was a relationship between a communication activity (i.e., tactic) and an outcome (especially learning), or (2) reframed in terms of potential future application. Finding an applied angle of basic science topics was especially common in the context of nanotechnology where issues of perceived risks and benefits were frequently discussed in the context of future consumer acceptance. It also, however, occurred in the context of neuroscience where there was an emphasis on how audiences perceive neuroscience imagery as a function of mental health/learning, and in the case of evolution where the focus was often related to education issues.

Further, in reading the abstracts (and many of the full articles), we developed the sense that, for example, neuroscience articles largely sought to speak to people already interested in neuroscience whereas astronomy focused articles sought to speak to those already interested in astronomy. This is a potential topic for more formal review of citation patterns, but our expectation is that such an effort would only quantify what our initial reading seems to show.

Discussion

We came away from our review of the selected research with the sense that no sustained literature on communication related to basic science exists within core science communication journals. In this regard, only a small fraction (less than 10%) of the articles in *Public Understanding of Science*, *Science Communication*, the *Journal of Science Communication*, and the *International Journal of Science Education, Part B: Communication and Public Engagement* seem to have any meaningful focus on basic science. Further, the basic-science-related articles that do exist seem to focus largely on science learning (i.e., comprehension or understanding) and risk/benefit beliefs with little broader connection to why learning or risk/benefit beliefs might be important towards achieving larger goals related to basic science. This means, for example, there was little basic-science-related research on the relationship between shorter-term outcomes such as learning and longer-term outcomes that we might want to see as a result of learning (or risk/benefit beliefs, or other potential communication outcomes). The focus on learning and risks and benefits also means there was very limited research on the broader range of potential outcomes that communicators could potentially affect through communication (e.g., changes in self-efficacy, risk/benefit beliefs, trust-related beliefs, identity beliefs, framing, emotions, etc.). There was similarly almost no focus on changes in science communicators' beliefs, feelings, frames, or behaviors.

Two additional limitations we see in the analyzed literature is that (1) much of the research seemed to focus on the particulars of the topic rather than seeking to provide generalizable information about how specific communication choices (e.g., how to set up an event or produce a document) might contribute to specific communication outcomes across basic science contexts, and (2) the particular challenges of communicating in the context of basic science was rarely the focus of attention. On this latter point, although the article topics were sometimes basic science related, the actual research often seemed to emphasize applied questions such as whether the application of the science might lead to risks or benefits to citizens. This was especially the case in research related to nanotechnology, neuroscience, and evolution. This approach may have made sense for the specific studies—and this is not a critique of such work—but one consequence of such approaches is that the overall community may be missing opportunities to develop evidence-based guidance.

A final potential limitation we noted was that the available research tended to focus on 'engagement' only in a generic sense. With a few notable exceptions (e.g., Tingay, 2018), there was little sense that the focus in the analyzed literature was specifically on using tools such as dialogue to encourage communication participants (including scientists or other science communicators) to slow down and think deeply (i.e., cognitively engage) in ways that might lead to the development of long-term evaluative beliefs.

As discussed in a companion essay, one path forward for those committed to expanding communication research related to basic science might be to identify specific long-term goals that are priorities for communicators working in the basic sciences. These might include goals such as ensuring funding support for scientific research and education, identifying key issues for further research, promoting consideration of scientific careers, or even simply ensuring strong relationships between scientific communities and the broader communities in which we all live. The expectation is that prioritizing specific long-term goals would allow researchers and practitioners to collectively think through the shorter-term outcomes (e.g., trust building, reframing, self-efficacy development, etc.) that theory and experience suggest might contribute to achieving those goals. They could then prioritize research aimed at identifying communication activities (i.e., tactics) that might lead to the shorter-term outcomes that enable goal achievement. These might include specific messages or content, ways of structuring events, effective styles, and specific channels or communicator characteristics that work especially well.

A further benefit of starting with goal identification is that it could enable research that spans across topics. In this regard, one might ask whether the factors that lead to support for funding in one area (e.g., astronomy) are similar to the factors that lead to support for alternative areas (e.g., any other basic or applied topic); or whether the factors that lead young people to consider scientific careers vary by topic. It might be that some issues come with specific affordances that make them especially effective for achieving some goals. For example, there appears to be a tendency within astronomy focused communication to suggest that the nature of astronomy lends itself to communication aimed at evoking emotions such as wonder or awe while also enabling the development of self-efficacy through the process of systematic observation. It might be that such features lend itself to science recruitment type goals for some types of young people. For other goals, other issues might have advantageous characteristics.

Table 1. Number of articles with keywords or coded content in articles (N = 2,365) from *Public Understanding of Science* (n = 1,061), *Science Communication* (n = 612), *Journal of Science Communication* (n = 513), and *International Journal of Science Education Part B: Communication and Public Engagement* (n = 179), with n = 41 removed due to lack of abstract data/cleaning.*

Keyword or Coded Content	Step 1: Keyword queries (N = 2,386)	Step 2: Human Coding to Confirm Relevance*	Step 3: Coding of Relevant Retained Articles to Determine the Type of Data Included in the Article (n = 161)**					
	Articles Returned	Article Retained (a = .81, N = 2,386)	Quantitative (a = .95)	Qualitative (a = .79)	Content Analysis (a = .81)	Theoretical (a = .65)	Case Study (a = .85)	Historical (a = .NA)
Astron+	28	25	7	5	6	2	5	1
Cosmol+	2	2	0	0	1	0	1	0
Galaxy	1	1	1	0	0	0	0	0
Neutrino	1	1	0	0	1	0	0	0
Particle	2	2	1	0	0	1	0	0
Planet+	9	6	1	1	2	0	2	0
Quark	2	1	0	0	0	0	1	0
Solar system	1	1	0	1	0	0	0	0
Astrophy+	2	2	2	1	0	0	0	0
Chemi+	22	14	5	4	5	2	1	0
Evolution+	60	29	4	2	9	10	2	2
Nanosci+	7	7	2	2	1	2	2	0
Nanotech+	63	60	22	16	11	9	7	0
Neuro+	22	15	2	4	4	2	2	1
Physics	45	24	7	6	3	4	5	3
True Total* **	237	161	47	37	35	26	21	6
Percentage	10%	7%	29%	23%	22%	16%	13%	4%

Notes: *Downloaded from Web of Science, ** Krippendorff's alpha for intercoder reliability with two coders (Step 2: n = 24, ~15% of step 1 articles; Step 3: ~30% of Step 2 articles). ***Given that many articles were coded to more than one keyword, the true total is the total number of unique articles.

Table 2. Number of articles with ‘applied science’ keywords (N = 2,386) from Public Understanding of Science (n = 1,061), Science Communication (n = 629), Journal of Science Communication (n = 513), and International Journal of Science Education Part B: Communication and Public Engagement (n = 183).*

Technology	650	**Sustainab+**	43	**Cancer**	15	**Geolog+**	4
Polic+	318	**Ecology**	42	**Clinic+**	15	**Endangered**	4
Education+	313	**Math+**	41	**Law**	14	**Storage**	4
Risk+	271	**Energy**	41	**Weather+**	14	**Hydrogen**	4
Fund	265	**Psychology**	38	**Corona+**	12	**Social Psychology**	3
Politic+	246	**Global warming**	38	**Autonomous**	11	**Carbon dioxide**	3
Govern+	243	**GM**	35	**Drug**	10	**Recycling**	3
Health+	233	**Biomed+**	35	**Chemic+**	10	**Wind**	3
Genetic+	215	**Animal+**	35	**GMO+**	9	**Car**	3
Climate	198	**Nuclear**	31	**Botan+**	9	**Turbine**	2
Environmental+	197	**Conservation**	29	**Fracking**	9	**Agron+**	1
Histor+	138	**Vaccin+**	28	**Renewable**	9	**Astrol+**	1
Medic+	121	**STEM Cell**	27	**Flu**	7	**Computer Scientists**	1
Food+	97	**Earth+**	26	**Physician**	7	**Aquatic**	1
Museum	93	**Patient**	25	**Curiosity**	7	**Carbon capture**	1
Accept+	90	**Epistemolog+**	24	**Invasive**	7	**Crispr**	1
Biotech+	86	**Clone**	24	**Artificial intelligence**	7	**Battery**	1
Engineer+	83	**Therap+**	22	**Vehicle**	7	**Solar Panel**	1
Genetically modified	75	**Species**	22	**Autism**	6	**Translational**	0
Regulat+	72	**Philosoph+**	21	**Ebola**	6	**Aerosp+**	0
Industry	71	**Synthetic**	20	**Chemistry**	6	**Astrob+**	0
Disease	69	**Zoo+**	19	**Hydraulic fracturing**	6	**Atomic**	0
Biolog+	66	**Diagnos+**	18	**H1N1+**	5	**Dam**	0
Threat+	63	**Mobile**	18	**Pharma+**	5	**Hydropower**	0
Religio+	61	**Embryo+**	17	**Cognitive science**	5	**Solar cell**	0
National Science	59	**Virus**	17	**Geoeng+**	5	**Automobile**	0
Career	52	**Doctor**	16	**SARS**	4	**Drone**	0
Agricul+	48	**Genetically engineered**	16	**Biosci+**	4		

Notes: # refers to the number of articles retrieved using the keyword from the title or abstract downloaded from Web of Science up to December 31, 2020.

Case Study 1: The Evidence Base for Science Communication about Astronomy, Astrophysics, and Space Science

Introduction

This short case study seeks to provide an overview of research about astronomy, astrophysics, and space science communication (hereafter just 'astronomy communication'). It specifically focuses on identifying research that a communication practitioner in this area might draw on to make evidence-based communication decisions. The case study argues that the astronomy communication available in core science communication journals focuses largely on near-term objectives such as increasing science knowledge and fostering positive emotions about science. It thus provides some guidance to practitioners on specific objectives while also potentially missing opportunities to study additional objectives that communicators might benefit from prioritizing (e.g., fostering risk/benefit beliefs, self-efficacy beliefs, trustworthiness beliefs, etc.). There also appear to be opportunities to connect potential near-term communication objectives to longer-term behavioral outcomes.

This case study on astronomy-related communication research was conducted alongside an effort to summarize the degree to which four core science communication research journals—*Public Understanding of Science (PUS)*, *Science Communication (SC)*, the *International Journal of Science Education-Part B (IJSE-B), Communication and Public Engagement*, and the *Journal of Science Communication (JoSC)*— included content focused on basic science research as of December 31, 2020. This broader study found that only about 7% (161 of 2,386) of the articles that appeared in these journals substantively focused on basic science. Of these, about 38 (i.e., less than 2%) seemed to be about astronomy.

Below, we describe the astronomy-focused research published in the four key science communication research journals. We also provide a brief overview of additional research found in other journals and qualitatively consider the degree to which this research seems similar or different from the research published in the core journals. These additional articles were identified by looking at citations in the journal articles from the core sample and standard keyword searches in Google Scholar and Web of Science. The goal was not to be exhaustive for this additional search but to identify highly visible research focused on astronomy-related communication.

Terminology: Goals Objectives, and Tactics

Goals: Drawing on research related to strategic communication (Hon, 1998), the term 'goal' is used to describe desired intentional behaviors (e.g., consider a career, donate to a cause, prioritize a research topic) and pseudo-behaviors (e.g., support funding, accept a decision) that a communicator might want to achieve from communication. Goal behaviors can be for the science communicator' group or another group. Goals are typically the result of achieving a range of different objectives.

Objectives: The term 'objective' is used to describe potential immediate and cumulative outcomes of communication activities such as changes to beliefs (e.g., science knowledge, risk/benefit beliefs, trustworthiness beliefs, social norms beliefs, self-efficacy beliefs), feelings (e.g., excitement, anger, etc.), issue framing (e.g., is this a health issue or an economic issue), and psychological processes (i.e., sustained cognitive engagement/attention). As with goals, science communicators can engage in communication where the objective is to change their own beliefs. Objectives typically mediate the relationship between tactics and goals.

Tactics: The term 'tactics' is used to describe any intentional choice that a science communicator might make to try to achieve communication objectives, including choices about behaviors (e.g., room set up, event timing, etc.), message content, and message style/tone/format, as well as channel and source choices. Also see table 1 in the companion essay and associated research (e.g., Besley et al., 2019) .

Overview

Our summary report found that the articles in the core journals included a mix of quantitative and qualitative studies about individuals' astronomy-related beliefs and feelings, as well as case studies and content analyses. The literature on astronomy-related communication outside of the core journals appears to be somewhat broader, including an emphasis on the goal of astronomy funding (i.e., support). Here too there seems to be a focus on a short set of communication objectives accompanied by an assumption that astronomy-related communication is special because of the universal nature of the topic (pun intended). Specifically, the tacit hypothesis seems to be that astronomy communication has a unique potential to evoke emotions such as awe and wonder, provides relatively straightforward opportunities for learning the value of systematic observation by both novices and experts around the world, and is relatively uncontroversial in comparison to issues that more directly affect peoples' day-to-day lives. Put differently, the idea seems to be that astronomy can serve as a distinctive gateway to science practice and appreciation. As an example, a chapter in a 2003 foundation text on *Astronomy Communication* includes a chapter focused on a NASA "Office of Public Outreach" for the Hubble Space Telescope that articulates the mission of "shar[ing] scientific knowledge of the universe in ways that inspire, excite, challenge, and educate" (Griffin, 2003). Ultimately, as will be discussed and similar to other basic science topics, the focus in the literature on a limited set of communication objectives and goals means that those who want to communicate in evidence-based in the context of astronomy need to draw extensively on research focused on other topics.

Primary Topics of Study in the Astronomy-Focused Science Communication Literature

Research on astronomy images: The most common astronomy communication research focus in the four core journals was about how astronomical images might help people learn and feel. Three researchers—Kimberley Kowal Arcand (NASA), Lisa F. Smith (University of Otago), and Megan Watzke (NASA)—and a range of collaborators are responsible for a substantial proportion of this research (i.e., six of the 38 astronomy articles in the core science communication journals). Initial research focused on the educational and aesthetic value of accompanying images with text descriptions, especially narrative text (Smith et al., 2011) as well as the potential value of public astronomy exhibits in non-traditional locations on "inspiration, personal connections, and small learning gains" (Arcand & Watzke, 2010; Arcand & Watzke, 2011). A later study of online images with a focus on mobile viewing found that "bigger is better" but that people generally like most images and prefer text that asks and answers a specific question, rather than providing a narrative (Smith et al., 2014). Aesthetic enjoyment and learning continued to be the focus in a study of deep space using images and videos (Smith et al., 2017) while a more recent study from this group on 3D models for communicating astronomy to the visually impaired similarly focused on user learning and enjoyment (Arcand et al., 2019). Beyond this research the core journals included an experiment that found that people who saw an interactive video were somewhat more supportive of a new telescope by NASA when compared to people who saw alternative text or no text (Weber et al., 2016). This last study is especially notable because it specifically focuses on a long-term communication goal (i.e., support) and not just near-term communication objectives such as learning and emotion.

Research on how various activities lead to specific objectives, especially learning and emotion: Research from the core science communication journals has sometimes touched on the potential effect of various potential communication activities (i.e., tactics) on potential communication objectives. This research has come from a variety of scholars and has also generally focused on the objectives of science learning and emotion. This includes, for example, a study that found small within-person effects of seeing an Einstein-focused dance activity on learning, interest, and emotion (as well as future event participation, a potential longer-term communication goal) (Grimberg et al., 2019), a case study of a dark matter exhibit that focused on experienced emotions (Trotta et al., 2020), and two studies showing that participating in citizen science projects related to astronomy had only limited effects on science learning (Masters et al., 2016; Raddick et al., 2019). Several youth-focused studies that examined science learning objectives suggested that a planetarium field trip led to "three dimensional learning" in a small group of 6-7 year-olds (Plummer & Small, 2018)and that a summer camp song choreography activity (Mangan et al., 2019), and a museum visit focused on gravity (Lelliott, 2014) resulted in some small gains in science knowledge. Beyond youth, a study of astronomy amateurs suggested the importance of organizations in the learning process, although knowledge creation was also discussed as a potential outcome of communication activities (Corin et al., 2017). A follow-up study emphasized the value of youth activities and organizations on similar topics (Corin et al., 2018).

One novel article in the core journals was a case study of how indigenous artists and astrophysicists in Australia spent time together discussing the universe and art in the context of a plan to build a large telescope on native land (Tingay, 2018). This article was unique in its emphasis on how interaction between two different groups was resulting in new insights (i.e., ways of thinking about astronomy) while also ensuring that the scientists involved were able to move forward with a telescope project in a way that responded to and was inclusive of perspectives from indigenous groups. From a strategic perspective, support and new insights might be understood as potential communication goals that occurred as a partial result of relationship building efforts (i.e., fostering mutual trustworthiness beliefs).

Content analysis research related to astronomy: Beyond studies of activities, eight of the 38 astronomy communication articles in the core journals focused on content analyses of news articles. Content analyses included studies of the metaphors used to discuss science with a substantial emphasis on articles related to astronomy and space (Christidou et al., 2004), as well as an article highlighting that astronomy and space topics were relatively common topics of coverage (Dutt & Garg, 2000) and a study of how NASA's Columbia disaster was covered (Sumpter & Garner, 2007). A key takeaway of these articles for practitioners might simply be that the topic of astronomy and space often generates relatively positive news coverage. Two history/theory-focused articles on Mexico emphasized the potential value of astronomical events in generating scientific interest and the potential for astronomers to use these events to interact with a range of different audiences (Biro, 2012, 2014; see also, Huang, 2017). On the other hand, a case study article on asteroids also highlighted the potential for a small group of scientists to overplay evidence to obtain funding (Mellor, 2010).

Beyond content analyses, two other articles in the core science communication journals include a case study focused on the portrayal of the female scientist in the film *Contact* that emphasized the challenges of such careers for women (Steinke, 1999) and a summary of a program by the United Kingdom's Royal Astronomical Society that argued that one of its programs was having positive impact on ensuring that a broad swath of U.K. residents have positive experiences with scientists (Miller et al., 2018). Neither article, however, appears to provide specific guidance to communication practitioners.

Beyond the Core Journals: There is somewhat extensive literature on astronomy communication outside of the core science communication journals. The heart of this work has appeared in the International Astronomical Union's *Communicating Astronomy with the Public* in-house journal. Although not published through a typical publisher, the open-access journal has published about 30 issues since 2007. The issues include a combination of practitioner reports, news, and informal case study-type reports, as well as more traditional academic research on astronomy communication. A non-systematic review of the content suggests that the research articles are similar in focus to what has appeared in the core journals with extensive focus on both learning and emotion-related outcomes, as well as occasional other topics. In addition, the journals *Space Policy* and *Astropolitics* have also sometimes published articles on public opinion about space-related funding with a focus on potential levers of support. Many of these have been by a small group of authors (Cobb, 2020; Steinberg, 2011, 2013; Whitman Cobb, 2011, 2015, 2020). The scope of the literature prevents a systematic review here but it is clear that there is a demand within the community for how to ensure long-term support for astronomy related initiatives (Ehrenfreund et al., 2010) and some research on such topics. It also appears that there is some interest in the astronomy community for considering public input into space-related policy decisions. Two 2017 studies, for example, reported on a “participatory technology assessment” project that sought to better understand public views about public priories related to Mars exploration (Bertrand et al., 2017) and asteroid collisions (Tomblin et al., 2017).

Conclusion

As noted, while a range of astronomy-focused studies related to communication clearly exist, this literature appears to emphasize a small range of near-term communication objectives related to learning and emotion (especially in the context of imagery) and has limited focus on long-term goals. This may mean there is a substantial opportunity for increased discussion about how to connect shorter-term objectives to substantive, longer-term goals. It is also noteworthy that the range of potential communication objectives discussed by the astronomy communication literature is somewhat narrow. This means there appears to be an opportunity for substantial work on other potential communication objectives addressed by communication research and practice in other fields. This might include trustworthiness-related beliefs, identity beliefs, risk and benefit beliefs, self-efficacy beliefs, and normative beliefs despite, as well as how issues are. Such work could focus on both public audiences and scientists themselves (e.g., what activities might change scientists’ beliefs, feelings, or framing of issues?) (see accompanying essay).

Also noteworthy is the untested hypothesis that the topic of astronomy has characteristics (i.e., affordances) that make it an especially useful tool for bringing people closer to science. As noted, the idea seems to be that the topic is relatively apolitical and that the act of observing through tools such as telescopes provides a way to introduce a wide range of people to the joys of systematic scientific observation. It might be interesting, from this perspective, to find ways to test this hypothesis with the expectation that astronomy may indeed provide opportunities for positive scientific experiences for some people whereas the features of other issues may be especially effective for others.

As with other basic science topics, it may also be that identifying clear audience-specific behavioral goals or near-term objectives would enable communication practitioners to identify communication tactics (e.g., specific messages, styles, or processes, etc.) that researchers could then explore and test. In doing so, it should be recalled that the astronomy community may wish to prioritize goals associated with changes in others’ behaviors (e.g., communication aimed at ensuring funding support and the use of science in decision-making, as well as youth career choice), as well as changes to the astronomy community’s behaviors (e.g., communication aimed assessing whether current research priorities and approaches are the best possible use of resources).

Case Study 2: The Evidence Base for Science Communication about Neuroscience

Introduction

This short case study seeks to provide an overview of research about neuroscience communication. People within the neuroscience community have frequently highlighted the importance of improving communication between neuroscientists and the communities within which they work (Heagerty, 2015; Illes et al., 2010; Leshner, 2011; Mitchell et al., 2021; Ramani, 2009). This specific case study also originates from a discussion about the degree to which there is a science communication literature that is specifically focused on basic science and that would support communication decision-making within the basic sciences. The case study therefore specifically focuses on identifying research that a communication practitioner in this area might draw on to make evidence-based communication decisions.

This case study on neuroscience-related communication research was conducted alongside an effort to summarize the degree to which four core science communication research journals—*Public Understanding of Science (PUS)*, *Science Communication (SC)*, the *International Journal of Science Education-Part B (IJSE-B), Communication and Public Engagement*, and the *Journal of Science Communication (JoSC)*— included content focused on basic science research as of December 31, 2020. This broader study found that only about 7% (161 of 2,386) of the articles that appeared in these journals substantively focused on basic science. Of these, about 15 seemed to be about neuroscience. These were primarily qualitative studies and content analyses. These 15 articles are discussed below alongside research from beyond the four core journals. The overall conclusion is that the neuroscience communication that currently exists tends to focus on applied issues related to health and wellness, touching tangentially on the underlying science. However, there remains an opportunity to consider building a focused body of neuroscience-specific communication research while exploring the degree to which research on communication related to other topics—including both science and non-science topics—speaks to the neuroscience community's priority goals for communication.

Below, we primarily describe the neuroscience-focused research published in four key science communication research journals. We also provide a brief overview of additional research found in other journals and qualitatively consider the degree to which this research is similar or different from the research published in the core journals. These articles were identified by looking at citations in the journal articles and standard keyword searches in Google Scholar and Web of Science. The goal was not to be exhaustive for this additional search but to identify highly visible research focused on neuroscience-related communication.

Overview

The evidence-based neuroscience-focused communication literature appears to include three main types of content: (1) how scientists and the public perceive neuroscience, with a focus on risks and benefit beliefs; (2) research on the degree to which neuroscience images could be misused as part of persuasive appeals; and (3) research focused on how exposure to neuroscience communication activities may affect learning and interest, especially in youth audiences. We did not see substantial research focused around achieving specific, long-term behavioral goals identified by the neuroscience community or research focused on objectives beyond fostering learning and excitement in external audiences. Similar to other fields, we have also not yet found research focused on how the neuroscience community was using communication to create opportunities to (re)shape their own beliefs, feelings, or frames *about neuroscience* (e.g., risk/benefit beliefs about neuroscience-derived therapeutic interventions), *themselves* (e.g., scientists' beliefs about their own self-efficacy or abilities), or *others* (e.g., beliefs about stakeholders' trustworthiness; normative beliefs about others' beliefs and behaviors).

Terminology: Goals Objectives, and Tactics

Goals: Drawing on research related to strategic communication (Hon, 1998), the term 'goal' is used to describe desired intentional behaviors (e.g., consider a career, donate to a cause, prioritize a research topic) and pseudo-behaviors (e.g., support funding, accept a decision) that a communicator might want to achieve from communication. Goal behaviors can be for the science communicator' group or another group. Goals are typically the result of achieving a range of different objectives.

Objectives: The term 'objective' is used to describe potential immediate and cumulative outcomes of communication activities such as changes to beliefs (e.g., science knowledge, risk/benefit beliefs, trustworthiness beliefs, social norms beliefs, self-efficacy beliefs), feelings (e.g., excitement, anger, etc.), issue framing (e.g., is this a health issue or an economic issue), and psychological processes (i.e., sustained cognitive engagement/attention). As with goals, science communicators can engage in communication where the objective is to change their own beliefs. Objectives typically mediate the relationship between tactics and goals.

Tactics: The term 'tactics' is used to describe any intentional choice that a science communicator might make to try to achieve communication objectives, including choices about behaviors (e.g., room set up, event timing, etc.), message content, and message style/tone/format, as well as channel and source choices.

Also see figure 1 in the companion essay and associated research (e.g., Besley et al., 2019) .

In addition to the topics described below, two articles that appeared in our search and that have garnered citation activity may merit particularly mention. One article did not include new data but attempted to argue that neuroscience can help us understand why stories can be useful in communication (Cormick, 2019). Another used ethnography to study an 'upstream' effort to engage a range of stakeholders on neuroscience imaging in the context of the potential for policy related to patient privacy. This second article is of particular interest because it was the only study we found that focused on a clear behavioral goal (i.e., the potential need to devote effort to developing policies related to neuroscience) and where the effort seemed to be on helping the neuroscience community improve their own thinking.

Primary Topics of Study in the Neuroscience-Focused Science Communication Literature

Research on how scientists and others perceive neuroscience. The four core science communication journals included only five articles that provided new evidence focused on the communication of neuroscience. These articles seemed aimed at contributing to broader discussions about science communication, rather than neuroscience.

- One of these was a study that used qualitative interviews with 24 U.S. neuroscientists to explore how they perceive their relationship with the news media (Koh et al., 2016). The study fits into part of a broader academic discussion about the degree to which scientists, across fields, may be prioritizing applied research topics to garner media attention. The key lesson practitioners might get from such work is simply to be aware that neuroscientists—like scientists in other areas—generally see value in obtaining press coverage. This might provide a justification for seeking to help neuroscientists with their outreach efforts. More critically, it is not clear that increased media coverage leads to research support.
- A second core-journal article used focus groups to explore how different groups, including neuroscientists, think about neuroscience with a focus on popular discourse around 'neuroplasticity' (Pickersgill et al., 2015). The core argument focused on how discussion about neuroscience might help understanding of how people use their everyday experiences to make sense of new scientific topics. The study suggested that participants focused on how neuroscience might be used to help specific types of people heal or improve. The practical implication might be that anyone trying to communicate about the basic science of neuroscience will need to recognize that most audiences will still tend to interpret the topic in applied terms. Communication efforts that fail to take this tendency into account are thus likely to face challenges.

The three other articles from the four core journals also used neuroscience as a backdrop to explore broader science communication issues, including how reporters address uncertainty when writing stories (Lehmkuhl & Peters, 2016), how institutional structures can shape communication choices (France et al., 2017), and the correction of misinformation (Smith & Seitz, 2019). All three articles, however, could be argued to have downplayed the neuroscience context to speak to questions that people in any area of science communication might find relevant. In the first case, Lehmkuhl and Peters (2016) noted that journalists will often omit discussions of uncertainty unless it is the focus of the story, while the second study highlights the value of embedding communication activities within an organization that can provide support (France et al., 2017). The misinformation article similarly simply showed that providing corrective information immediately after misinformation could help prevent uptake of incorrect beliefs, a result that is relevant beyond neuroscience-specific communication (Smith & Seitz, 2019). An additional brief case study also addressed a conference on the relationship between science communication and scientific culture (Costanzo & Golombek, 2020).

Outside of the core journals, a variety of articles appear to have focused on public perceptions of neuroscience (O'Connor & Joffe, 2013a), as well as media coverage of neuroscience (O'Connor & Joffe, 2013b, 2014, 2015; O'Connor et al., 2012). As with the articles from the core journals, however, much of the focus appears to have been on applied questions about how people make sense of neuroscience in the context of health and well-being. The available work does not appear to involve substantial testing of specific messages or other communication tactics. Instead, the research appears to seek to provide readers with an understanding of contemporary discussions and thinking around neuroscience, especially neuroscience media coverage.

Research on neuroscience images and persuasion. One consistent theme in the literature on neuroscience communication is a concern that neuroscience images (i.e., colorful fMRI brain scans) may exert undue influence on peoples' perceptions of the efficacy of neuroscience in explaining human behavior. Within the four core science communication journals, five studies focused on this topic. Two essays reviewed the problem without introducing new data (Baker et al., 2017; Rodriguez, 2006), and two studies explored the issue using new data (Gruber & Dickerson, 2012; Popescu et al., 2016). Both used experimental methods and failed to find evidence that images negatively affected respondents in substantial ways. However, both studies also involved small samples of undergraduate students so it remains possible that interesting effects might be found in future studies. Another study looked at media coverage of functional magnetic resonance imaging (fMRI) and how images and other aspects of how poor quality coverage can generate ethical concerns (Racine et al., 2006).

Research outside the core journals has also sought to explore the degree to which brain scan images might bias judgements, with limited findings (Baker et al., 2013; Farah & Hook, 2013; McCabe & Castel, 2008). Another set of studies, including one from the core journal set and another from outside the core, used rhetorical methods and theory to examine relevant media coverage in which images were used in potentially persuasive ways (Gruber, 2021; Gruber, 2017). Another article outside the core journals used a qualitative analysis of media content to argue that many neuroscience-related images do not always involve brain images, but may still be problematic in how they portray neuroscientific findings (Whiteley, 2012). The practical implication of such research might simply be that neuroscience communicators should use images judiciously to avoid inadvertently advancing arguments based on non-relevant factors.

Research on youth-focused communication activities. The third area where there seemed to be a small amount of neuroscience-focused communication research (mostly outside of the core journals) involved evaluation-type studies focused on assessing the impact of specific events. These often focused on youth audiences. Within the core journals, just one such article appeared and argued that a multi-week, in-class activity focused (loosely) on neuroscience related to color helped high school students learn about science and develop self-efficacy and interest in science (Ruiz-Mallen et al., 2016). However, this article's focus on learning, interest, and self-efficacy appeared consistent with other articles that appeared outside the core journals analyzed and generally demonstrated that well-run program can have small, positive effects (e.g., Sarvary & Gifford, 2017; Zardetto-Smith et al., 2006; Zardetto-Smith et al., 2002). A somewhat different study focused on how to get existing science students to communicate clearly by teaching them to write neuroscience-focused haikus (Pollack & Korol, 2013).

The practical implications of these studies may simply be to show that it is possible to shape participants beliefs and feelings through communication activities about neuroscience. These studies provide example activities, however, but do not specifically test communication choices.

Further, they do not appear to build on each in a systematic way or seek to connect to broader goals that the neuroscience community might seek to achieve, beyond recruitment.

Conclusion

A small number of evidence-focused neuroscience-related science communication studies exist but there remains a potential opportunity for a sustained effort to develop evidence-based insight to help specifically advance neuroscience-related communication priorities. The field might, in this regard, benefit from research aimed at helping neuroscience communicators make evidence-based communication decisions, including decisions about how to deeply engage stakeholders in meaningful relationship building through ongoing dialogue. As with other basic science topics, it may be that identifying clear audience-specific behavioral goals or near-term objectives would enable communication practitioners to identify communication tactics (e.g., specific messages, styles, or processes, etc.) that researchers could then explore and test. In doing so, it should be recalled that the neuroscience may wish to prioritize goals associated with changes in both others' behaviors (e.g., communication aimed at ensuring funding support and the use of science in decision-making, as well as youth career choice), *as well as* changes to neuroscientists behaviors (e.g., communication aimed assessing whether current research priorities and approaches are the best possible use of resources). As is argued in a companion essay, an additional advantage of identifying clear goals for neuroscience communication is that doing so could help neuroscience-focused communicators draw on existing and new research into communication topics other than neuroscience.

Author Information

Dr. John C. Besley is the Ellis N. Brandt Chair of Public Relations. He has published more than 100 articles and book chapters on science communication and public engagement. This work has included both research on public opinion about science and science communicators' views about public communication. He is the associate editor for risk communication for the journal *Risk Analysis* and is on the editorial boards of *Public Understanding of Science*, *Science Communication*, *Environmental Communication*, and the *Journal of Risk Research*.

Dr. Karen Peterman is President of Karen Peterman Consulting, Co., an external evaluation and educational research consulting firm in Durham, NC. She has published more than 20 articles and book chapters on informal science learning and public engagement. This work has included a focus on evaluation methods and instruments that can provide meaningful data in the context of informal learning spaces, and visitor studies that describe those who participate in events and event outcomes.

Dr. Allison Black-Maier is a Research Associate at Karen Peterman Consulting, Co., an external evaluation and educational research consulting firm in Durham, NC. Her evaluation work focuses on informal STEM learning and her research interests include science communication and public engagement. Her work also involves developing relational databases that allow programs to track their processes and outcomes.

Dr. Jane Robertson Evia is a Collegiate Associate Professor in the Department of Statistics and a Fellow at the Center for Communicating Science at Virginia Tech. Her research interests include science communication, public engagement in science, statistics education, and data visualization. She has published articles on statistics education, public engagement with science, interactive visual analytics, and informal science learning. She has also offered workshops on data visualization and storytelling; data collection, management, and analysis; and statistics education.

Funding Information

This work was supported by The Kavli Foundation, as part of the Science Public Engagement Partnership (SciPEP) with the Department of Energy, to advance scholarship on communication and public engagement on basic science. Opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funder. Additional SciPEP resources area available at scipep.org.

References

Arcand, K., & Watzke, M. (2010). Bringing the universe to the street. A preliminary look at informal learning implications for a large-scale non-traditional science outreach project [Article]. *Journal of Science Communication, 9*(2), 1-13. https://doi.org/10.22323/2.09020201

Arcand, K. K., Jubett, A., Watzke, M., Price, S., Williamson, K. T. S., & Edmonds, P. (2019). Touching the stars: Improving NASA 3D printed data sets with blind and visually impaired audiences [Article]. *Journal of Science Communication, 18*(4). https://doi.org/10.22323/2.18040201

Arcand, K. K., & Watzke, M. (2011). Creating Public Science With the From Earth to the Universe Project. *Science Communication, 33*(3), 398-407. https://doi.org/10.1177/1075547011417895

Baker, D. A., Schweitzer, N. J., Risko, E. F., & Ware, J. M. (2013). Visual Attention and the Neuroimage Bias. *PLoS ONE, 8*(9), e74449. https://doi.org/10.1371/journal.pone.0074449

Baker, D. A., Ware, J. M., Schweitzer, N. J., & Risko, E. F. (2017). Making sense of research on the neuroimage bias. *Public Understanding of Science, 26*(2), 251-258. https://doi.org/10.1177/0963662515604975

Bennett, N., Dudo, A., Yuan, S., & Besley, J. C. (2019). Chapter 1: Scientists, trainers, and the strategic communication of science. In Theory and Best Practices in Science Communication Training (pp. 9-31). Routledge.

Bertrand, P., Pirtle, Z., & Tomblin, D. (2017). Participatory technology assessment for Mars mission planning: Public values and rationales. *Space Policy, 42*, 41-53. https://doi.org/10.1016/j.spacepol.2017.08.004

Besley, J. C., Dudo, A., & Yuan, S. (2018). Scientists' views about communication objectives. Public Understanding of Science, 27(6), 708-730. https://doi.org/10.1177/0963662517728478

Besley, J. C., Newman, T., Dudo, A., & Tiffany, L. A. (2020). Exploring Scholars' Public Engagement Goals in Canada and the United States. Public Understanding of Science, 29(8), 855-867. https://doi.org/10.1177/0963662520950671

Besley, J. C., O'Hara, K., & Dudo, A. (2019). Strategic science communication as planned behavior: Understanding scientists' willingness to choose specific tactics. PLoS ONE, 14(10), e0224039. https://doi.org/10.1371/journal.pone.0224039

Biro, S. (2012). Astronomy by Correspondence: A Study of the Appropriation of Science by the Mexican Public (1927-1947). *Science Communication, 34*(6), 803-819. https://doi.org/10.1177/1075547012438466

Biro, S. (2014). Natural Wonders and Scientific Performance: A Mexican Eclipse and Its Uses. *Science Communication, 36*(6), 735-753. https://doi.org/10.1177/1075547014554960

Christidou, V., Dimopoulos, K., & Koulaidis, V. (2004). Constructing social representations of science and technology: the role of metaphors in the press and the popular scientific magazines. *Public Understanding of Science, 13*(4), 347-362. https://doi.org/10.1177/0963662504044108

Cobb, W. N. W. (2020). The South and NASA: Public Opinion Differences and Political Consequence. *Astropolitics, 18*(2), 122-143. https://doi.org/10.1080/14777622.2020.1786303

Corin, E. N., Jones, M. G., Andre, T., & Childers, G. M. (2018). Characteristics of lifelong science learners: an investigation of STEM hobbyists [Article]. *International Journal of Science Education, Part B: Communication and Public Engagement, 8*(1), 53-75. https://doi.org/10.1080/21548455.2017.1387313

Corin, E. N., Jones, M. G., Andre, T., Childers, G. M., & Stevens, V. (2017). Science hobbyists: active users of the science-learning ecosystem [Article]. *International Journal of Science Education, Part B: Communication and Public Engagement, 7*(2), 161-180. https://doi.org/10.1080/21548455.2015.1118664

Cormick, C. (2019). Who doesn't love a good story? - What neuroscience tells about how we respond to narratives [Article]. *Journal of Science Communication, 18*(5). https://doi.org/10.22323/2.18050401

Costanzo, G. D., & Golombek, D. A. (2020). The quest for scientific culture [Article]. *Journal of Science Communication, 19*(1). https://doi.org/10.22323/2.19010601

Dutt, B., & Garg, K. C. (2000). An overview of science and technology coverage in Indian English-language dailies. *Public Understanding of Science, 9*(2), 123-140. https://doi.org/10.1088/0963-6625/9/2/303

Ehrenfreund, P., Peter, N., & Billings, L. (2010). Building long-term constituencies for space exploration: The challenge of raising public awareness and engagement in the United States and in Europe. *Acta Astronautica, 67*(3), 502-512. https://doi.org/https://doi.org/10.1016/j.actaastro.2010.03.002

Farah, M. J., & Hook, C. J. (2013). The Seductive Allure of “Seductive Allure”. *Perspectives on Psychological Science, 8*(1), 88-90. https://doi.org/10.1177/1745691612469035

France, B., Cridge, B., & Fogg-Rogers, L. (2017). Organisational culture and its role in developing a sustainable science communication platform [Article]. *International Journal of Science Education, Part B: Communication and Public Engagement, 7*(2), 146-160. https://doi.org/10.1080/21548455.2015.1106025

Griffin I. (2003) The Hubble Space Telescope Education and Outreach Program. In: Heck A., Madsen C. (eds) Astronomy Communication. Astrophysics and Space Science Library, vol 290. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-0801-2_8

Grimberg, B. I., Williamson, K., & Key, J. S. (2019). Facilitating scientific engagement through a science-art festival [Article]. *International Journal of Science Education, Part B: Communication and Public Engagement, 9*(2), 114-127. https://doi.org/10.1080/21548455.2019.1571648

Gruber, D. (2021). Neurons in sparkling space: scientific objectivity and ‘blurry’ images in neuroscience [Article]. *Journal of Science Communication, 20*(1), Article A02. https://doi.org/10.22323/2.20010202

Gruber, D., & Dickerson, J. A. (2012). Persuasive images in popular science: Testing judgments of scientific reasoning and credibility. *Public Understanding of Science, 21*(8), 938-948. https://doi.org/10.1177/0963662512454072

Gruber, D. R. (2017). Three Forms of Neurorealism: Explaining the Persistence of the "Uncritically Real" in Popular Neuroscience News. *Written Communication, 34*(2), 189-223. https://doi.org/10.1177/0741088317699899

Heagerty, B. (2015). Dissemination Does Not Equal Public Engagement. *The Journal of Neuroscience, 35*(11), 4483-4486. https://doi.org/10.1523/jneurosci.4408-14.2015

Hon, L. C. (1998). Demonstrating effectiveness in public relations: Goals, objectives, and evaluation. *Journal of Public Relations Research, 10*(2), 103-135. https://doi.org/10.1207/s1532754xjprr1002_02

Huang, H.-F. (2017). Transferring scientific discovery to the public: The intramercurial planet Vulcan in 1860. *Public Understanding of Science, 26*(3), 393-397. https://doi.org/10.1177/0963662516679045

Illes, J., Moser, M. A., McCormick, J. B., Racine, E., Blakeslee, S., Caplan, A., Hayden, E. C., Ingram, J., Lohwater, T., McKnight, P., Nicholson, C., Phillips, A., Sauvé, K. D., Snell, E., & Weiss, S. (2010). Neurotalk: improving the communication of neuroscience research. *Nature Reviews Neuroscience, 11*(1), 61-69. https://doi.org/10.1038/nrn2773

Koh, E. J., Dunwoody, S., Brossard, D., & Allgaier, J. (2016). Mapping Neuroscientists' Perceptions of the Nature and Effects of Public Visibility. *Science Communication, 38*(2), 170-196. https://doi.org/10.1177/1075547016635180

Lehmkuhl, M., & Peters, H. P. (2016). Constructing (un-)certainty: An exploration of journalistic decision-making in the reporting of neuroscience. *Public Understanding of Science, 25*(8), 909-926. https://doi.org/10.1177/0963662516646047

Lelliott, A. (2014). Understanding Gravity: The Role of a School Visit to a Science Centre [Article]. *International Journal of Science Education, Part B: Communication and Public Engagement, 4*(4), 305-322. https://doi.org/10.1080/21548455.2013.818260

Leshner, A. I. (2011). Bridging neuroscience and society: Research, Education, and Broad Engagement. In J. Illes & B. J. Sahakian (Eds.), *Oxford Handbook of Neuroethics*. Oxford University Press. http://ebookcentral.proquest.com/lib/michstate-ebooks/detail.action?docID=797732

Mangan, J. M., Newman, D., Doss, K. B., & Virani, S. N. (2019). Improving science content learning with choreographed songs at an astronomy summer camp [Article]. *International Journal of Science Education, Part B: Communication and Public Engagement, 9*(2), 101-113. https://doi.org/10.1080/21548455.2019.1571257

Masters, K., Oh, E. Y., Cox, J., Simmons, B., Lintott, C., Graham, G., Greenhill, A., & Holmes, K. (2016). Science learning via participation in online citizen science [Article]. *Journal of Science Communication, 15*(3), Article A07. https://doi.org/10.22323/2.15030207

McCabe, D. P., & Castel, A. D. (2008). Seeing is believing: The effect of brain images on judgments of scientific reasoning. *Cognition, 107*(1), 343-352. https://doi.org/https://doi.org/10.1016/j.cognition.2007.07.017

Mellor, F. (2010). Negotiating uncertainty: asteroids, risk and the media. *Public Understanding of Science, 19*(1), 16-33. https://doi.org/10.1177/0963662507087307

Miller, S., Bowler, S., & Kanani, S. (2018). RAS200 - engaging citizens with astronomy across cultural divides [Article]. *Journal of Science Communication, 17*(4), Article C03. https://doi.org/10.22323/2.17040303 Plummer, J. D., & Small, K. J. (2018). Using a planetarium fieldtrip to engage young children in three-dimensional learning through representations, patterns, and lunar phenomena. *International Journal of Science Education, Part B, 8*(3), 193-212. https://doi.org/10.1080/21548455.2018.1438683

Mitchell, A. S., Hartig, R., Basso, M. A., Jarrett, W., Kastner, S., & Poirier, C. (2021). International primate neuroscience research regulation, public engagement and transparency opportunities. *NeuroImage, 229*, 117700. https://doi.org/https://doi.org/10.1016/j.neuroimage.2020.117700

O'Connor, C., & Joffe, H. (2013a). How has neuroscience affected lay understandings of personhood? A review of the evidence. *Public Understanding of Science, 22*(3), 254-268. https://doi.org/10.1177/0963662513476812

O'Connor, C., & Joffe, H. (2013b). Media representations of early human development: Protecting, feeding and loving the developing brain. *Social Science & Medicine, 97*, 297-306. https://doi.org/10.1016/j.socscimed.2012.09.048

O'Connor, C., & Joffe, H. (2014). Gender on the Brain: A Case Study of Science Communication in the New Media Environment. *PLoS ONE, 9*(10), Article e110830. https://doi.org/10.1371/journal.pone.0110830

O'Connor, C., & Joffe, H. (2015). How the Public Engages With Brain Optimization: The Media-mind Relationship. *Science Technology & Human Values, 40*(5), 712-743. https://doi.org/10.1177/0162243915576374

O'Connor, C., Rees, G., & Joffe, H. (2012). Neuroscience in the Public Sphere. *Neuron, 74*(2), 220-226. https://doi.org/https://doi.org/10.1016/j.neuron.2012.04.004

Pickersgill, M., Martin, P., & Cunningham-Burley, S. (2015). The changing brain: Neuroscience and the enduring import of everyday experience. *Public Understanding of Science, 24*(7), 878-892. https://doi.org/10.1177/0963662514521550

Pollack, A. E., & Korol, D. L. (2013). The use of haiku to convey complex concepts in neuroscience. *Journal of undergraduate neuroscience education : JUNE : a publication of FUN, Faculty for Undergraduate Neuroscience, 12*(1), A42-48. <Go to ISI>://MEDLINE:24319390

Popescu, M., Thompson, R. B., Gayton, W. F., & Markowski, V. (2016). A reexamination of the neurorealism effect: The role of context [Article]. *Journal of Science Communication, 15*(6), 1-8. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85009843932&partnerID=40&md5=b5ca95795200937dc362ec93427cdb8f

Racine, E., Bar-Ilan, O., & Illes, J. (2006). Brain Imaging: A Decade of Coverage in the Print Media. *Science Communication, 28*(1), 122-143. https://doi.org/10.1177/1075547006291990

Raddick, M. J., Prather, E. E., & Wallace, C. S. (2019). Galaxy zoo: Science content knowledge of citizen scientists. *Public Understanding of Science, 28*(6), 636-651. https://doi.org/10.1177/0963662519840222

Ramani, D. (2009). The brain seduction: The public perception of neuroscience [Article]. *Journal of Science Communication, 8*(4). https://doi.org/10.22323/2.08040101

Rodriguez, P. (2006). Talking brains: a cognitive semantic analysis of an emerging folk neuropsychology. *Public Understanding of Science, 15*(3), 301-330. https://doi.org/10.1177/0963662506063923

Ruiz-Mallen, I., Riboli-Sasco, L., Ribrault, C., Heras, M., Laguna, D., & Perie, L. (2016). Citizen Science: Toward Transformative Learning. *Science Communication, 38*(4), 523-534. https://doi.org/10.1177/1075547016642241

Sarvary, M. A., & Gifford, K. M. (2017). The Benefits of a Real-Time Web-Based Response System for Enhancing Engaged Learning in Classrooms and Public Science Events. *Journal of undergraduate neuroscience education : JUNE : a publication of FUN, Faculty for Undergraduate Neuroscience, 15*(2), E13-E16. <Go to ISI>://MEDLINE:28690444

Smith, C. N., & Seitz, H. H. (2019). Correcting misinformation about neuroscience via social media. *Science Communication, 41*(6), 790-819. https://doi.org/10.1177/1075547019890073

Smith, L. F., Arcand, K. K., Smith, R. K., Bookbinder, J., & Smith, J. K. (2017). Capturing the many faces of an exploded star: Communicating complex and evolving astronomical data [Article]. *Journal of Science Communication, 16*(5), Article A02. https://doi.org/10.22323/2.16050202

Smith, L. F., Arcand, K. R., Smith, J. K., Smith, R. K., Bookbinder, J., & Watzke, M. (2014). Examining perceptions of astronomy images across mobile platforms [Article]. *Journal of Science Communication, 13*(2). https://doi.org/10.22323/2.13020201

Smith, L. F., Smith, J. K., Arcand, K. K., Smith, R. K., Bookbinder, J., & Keach, K. (2011). Aesthetics and Astronomy: Studying the Public's Perception and Understanding of Imagery From Space. *Science Communication, 33*(2), 201-238. https://doi.org/10.1177/1075547010379579

Steinberg, A. (2011). Space policy responsiveness: The relationship between public opinion and NASA funding. *Space Policy, 27*(4), 240-246. https://doi.org/10.1016/j.spacepol.2011.07.003

Steinberg, A. (2013). Influencing public opinion of space policy: Programmatic effects versus Education effects. *Astropolitics, 11*(3), 187-202. https://doi.org/10.1080/14777622.2013.841534

Steinke, J. (1999). Women scientist role models on screen - A case study of contact. *Science Communication, 21*(2), 111-136. https://doi.org/10.1177/1075547099021002002

Sumpter, R. S., & Garner, J. T. (2007). Telling the Columbia story - Source selection in news accounts of a shuttle accident. *Science Communication, 28*(4), 455-475. https://doi.org/10.1177/1075547007302306

Tingay, S. (2018). Indigenous Australian artists and astrophysicists come together to communicate science and culture via art [Article]. *Journal of Science Communication, 17*(4), Article C02. https://doi.org/10.22323/2.17040302

Tomblin, D., Pirtle, Z., Farooque, M., Sittenfeld, D., Mahoney, E., Worthington, R., Gano, G., Gates, M., Bennett, I., Kessler, J., Kaminski, A., Lloyd, J., & Guston, D. (2017). Integrating public deliberation into engineering systems: Participatory technology assessment of NASA's Asteroid Redirect Mission. *Astropolitics, 15*(2), 141-166. https://doi.org/10.1080/14777622.2017.1340823

Trotta, R., Hajas, D., Camargo-Molina, J. E., Cobden, R., Maggioni, E., & Obrist, M. (2020). Communicating cosmology with multisensory metaphorical experiences [Article]. *Journal of Science Communication, 19*(2), Article N01. https://doi.org/10.22323/2.19020801

Weber, R., Dinc, S., & Williams, M. (2016). Americans' Support for NASA's James Webb Space Telescope: Effects of Traditional Texts Compared to Interactive Media. *Science Communication, 38*(5), 601-625. https://doi.org/10.1177/1075547016663001

Whiteley, L. (2012). Resisting the revelatory scanner? Critical engagements with fMRI in popular media. *Biosocieties, 7*(3), 245-272. https://doi.org/10.1057/biosoc.2012.21

Whitman Cobb, W. N. (2011). Who's supporting space activities? An 'issue public' for US space policy. *Space Policy, 27*(4), 234-239. https://doi.org/10.1016/j.spacepol.2011.09.007

Whitman Cobb, W. N. (2015). Trending now: Using big data to examine public opinion of space policy. *Space Policy, 32*, 11-16. https://doi.org/10.1016/j.spacepol.2015.02.008

Whitman Cobb, W. N. (2020). Stubborn stereotypes: Exploring the gender gap in support for space. *Space Policy, 54*, 101390. https://doi.org/10.1016/j.spacepol.2020.101390

Zardetto-Smith, A. M., Mu, K., Carruth, L. L., & Frantz, K. J. (2006). Brains Rule!: a model program for developing professional stewardship among neuroscientists. *CBE life sciences education, 5*(2), 158-166. https://doi.org/10.1187/cbe.05-09-0116

Zardetto-Smith, A. M., Mu, K. L., Phelps, C. L., Houtz, L. E., & Royeen, C. B. (2002). Brains rule! Fun equals learning equals neuroscience literacy. *Neuroscientist, 8*(5), 396-404. https://doi.org/10.1177/107385802236965