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# Assessing the Scholarship of Public Engagement with Basic Science

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# Executive Summary

Based on a request from The Kavli Foundation in cooperation with the Department of Energy, we present a landscape assessment of a) what research exists on public engagement with basic science research in the Science, Technology Engineering, and Mathematics (STEM) peer-reviewed literature, b) trends in U.S. public opinion related to basic science research, and c) an in-depth review of public engagement activities in two specific fields: biotechnology and nanoscience.

First, we analyzed various secondary public opinion data sources to gauge how public attitudes and opinions of basic science and related concepts are measured, and what insight they can provide for the context of public engagement with basic science. One of the key trends that emerged was overall strong support among the U.S. public for federal funding of basic science research. Between 1985 and 2018, nearly 85% of the U.S. public said they "strongly agree" or "agree" that "scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government." However, there is a lack of public opinion data measuring directly how the public thinks and feels about basic science research and applied science research.

Second, our findings suggest that public engagement work doesn't appear frequently in field-specific STEM journals, and actually, its footprint might be even smaller than we report due to the number of false positives our manual coding revealed. Nonetheless, we do find that examples do appear sporadically, but mainly in journals that focus specifically on education contexts. Likewise, among those examples that have a public engagement focus, the focus is less on basic science than it is on more applied concepts. Furthermore, our analysis of case studies on public engagement related to biotechnology and nanoscience reveal that overall public engagement activities across these fields are initiated and supported by funding sources and focus on incorporating the public early in the development of specific technologies. In the context of nanoscience and biotechnology, the focus of public engagement almost immediately shifted to public engagement around applications.

Moving forward, more research is needed to understand how the public thinks about basic science (even if they might not use the same label), and if a distinction exists in the mind of the public compared to applied science. Second, very little research exists on public engagement, broadly, and basic science, specifically, in the discipline specific STEM journals. The scientific community needs to be much more transparent with participants and the broader public about their motivations and goals for public engagement with basic science. Simply building support for or excitement about science that might produce applications with disproportionate impacts on vulnerable populations is shortsighted at best and unethical at worst. As our analysis of trends in public opinion suggest, support for basic research funding remains strong and consistent, and the public has an overall positive sentiment towards basic science research, although sentiment is no different than applied research. Public engagement efforts therefore need to consider the outcomes of public engagement activities, and not only how these activities lead to changes in attitude, opinion, and behavior among the public, but also among the scientists and the work that they do.

# Introduction

This document presents the results of a landscape assessment of the science communication and public engagement scholarship as it pertains to discovery research (basic science). The approach is to understand the extent to which and in what way science communication and public engagement scholarship focuses on science where the immediate value and application are not (yet) clear. In doing so, we provide recommendations for how the community of science communication researchers and practitioners approach basic science research.

This document is organized into three main parts:

1. **Expert review of public opinion trends.**
   First, we provide an expert review of the literature on public opinion trends on knowledge and attitudes about basic science research as well as perceptions of and support for basic science research funding. This summary includes a targeted search of the public opinion trends via the iPoll database as well as an analysis of secondary databases.
2. **Systematic review of public engagement scholarship in STEM journals.**
   Second, we investigate to what extent public engagement with basic science is covered in journals across STEM fields and disciplines. In this section, we discuss how we selected journals and developed search terms to ensure we were casting the widest net of journals and articles to examine. We present our major findings relating the scope of scholarship pertaining to public engagement with basic science.
3. **Two ‘deep dive’ case studies.**
   Third, drawing on both the systematic review of relevant science communication literature as well as broader literature identified by the research team based on our expertise and targeted literature searches, we provide two case studies on the topics of 1) Biotechnology and 2) Nanoscience.

# Part 1: U.S. Public Opinion on Basic Sciences

Basic science, or science done for the sake of "acquiring new knowledge of the underlying foundations of phenomena and observable facts" (OECD, 2015) is the mechanism by which science advances. However, basic science relies on funding and support, primarily from the federal government. Both of these can be arguably impacted by public opinion. The public can prioritize and elect officials who support basic science research, for example, or policymakers might evaluate and predict public sentiment on basic science and act accordingly (Stimson et al., 1995). At the very least, public opinion may indirectly influence the time, attention, and funding that basic science receives from U.S. leadership.

At the same time, funding sources are changing. Funding for basic science grew between 2017 and 2018 within some U.S. federal agencies, but it stayed close to the same or dropped in some high-spending agencies (Table 1). Also, these federal sources in fact make up less and less of the total percent of basic science funding. The federal government funded 70% of basic science research in the 1960s and 1970s, but that figure dipped below 50% in 2013 in favor of corporate, university, and philanthropy funding sources (Mervis, 2017).

| Agency | 2017 (Million $) | | 2018 (Million $) | | % Change | |
|---|---|---|---|---|---|---|
| | Basic | Applied | Basic | Applied | Basic | Applied |
| All | 33,265 | 36,376 | 33,711 | 37,550 | 1.3 | 3.2 |
| Department of Agriculture | 965 | 1,251 | 1,006 | 1,335 | 4.3 | 6.7 |
| Department of Defense | 2,110 | 5,068 | 2,261 | 5,429 | 7.2 | 7.1 |
| Department of Energy | 4,494 | 4,861 | 4,930 | 6,451 | 9.7 | 32.7 |
| Department of Health and Human Services | 16,700 | 16,977 | 16,733 | 16,720 | 0.2 | -1.5 |
| National Aeronautics and Space Administration | 3,425 | 2,319 | 3,712 | 2,521 | 8.4 | 8.7 |
| National Science Foundation | 4,739 | 778 | 4,279 | 670 | -9.7 | -13.8 |

**Table 1**. Federal agencies tend to fund basic and applied science at similar rates, though the National Science Foundation and the Department of Health and Human Services both decreased their basic science funding between 2017 and 2018.

This uncertainty, coupled with an increased focus on science communication and engagement, might lead science communities to wonder whether basic science engagement would have any impact. Of course, we know that simply educating the public on science issues does not directly result in higher opinions of science (Scheufele, 2014; Wynne, 2006). Instead, to be meaningful and impactful, many have suggested that science engagement take on a more collaborative, dialogical tone (Burns et al., 2003). By definition, those dialogic models have to be context-dependent, recognizing that scientific and non-scientific groups apply different meanings and priorities to science.

This type of science engagement requires time and effort and probably takes on different characteristics each time it is applied. That said, for any type of science engagement to have an impact, it is important to understand differences in public opinion. Current and past public

opinion on basic science can offer some insight into current basic science support levels and how those might differ across groups.

The National Center for Science and Engineering Statistics (NCSES) first gathered public opinion of basic science in 1985 with the question, “Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government.” A steady and even increasing percent of the U.S. population agrees or strongly agrees with this statement, hovering around 80-85% between 1985 and 2018 (Figure 1a). Building on that, the picture is even more nuanced, with strong support (those who “strongly agree” that basic science is necessary) increasing over time (Figure 1b).

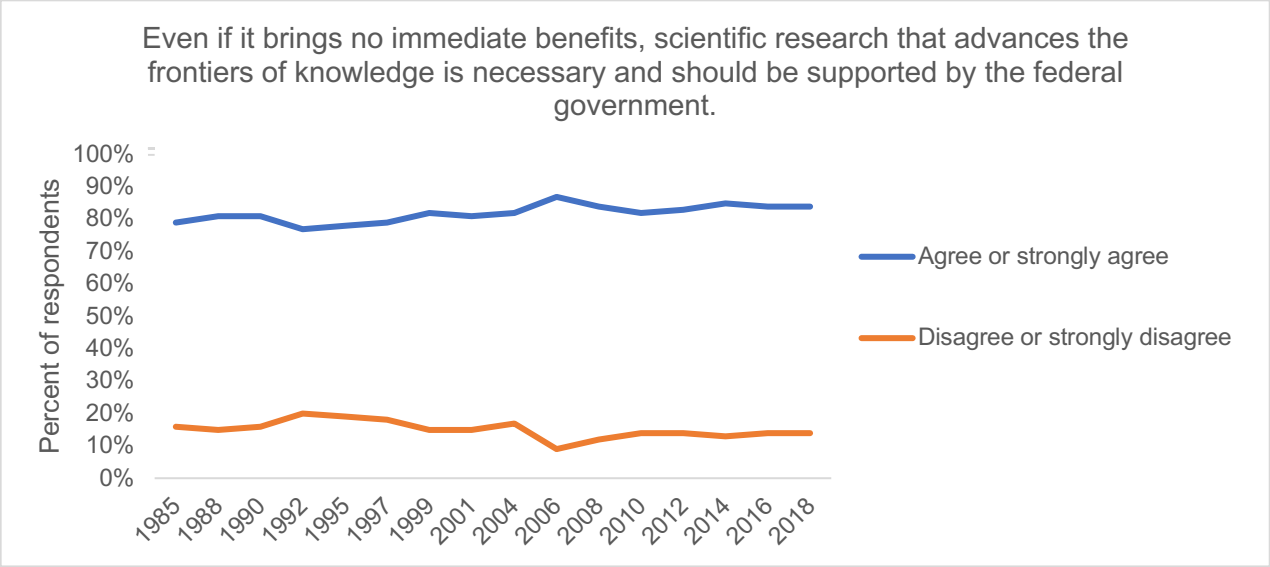



**Figure 1a**. Survey responses to the question, “Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government.”
Source: GSS (2006-2018), University of Michigan, Survey of Consumer Attitudes (2004) - National Science Foundation, National Center for Science and Engineering Statistics (2019)

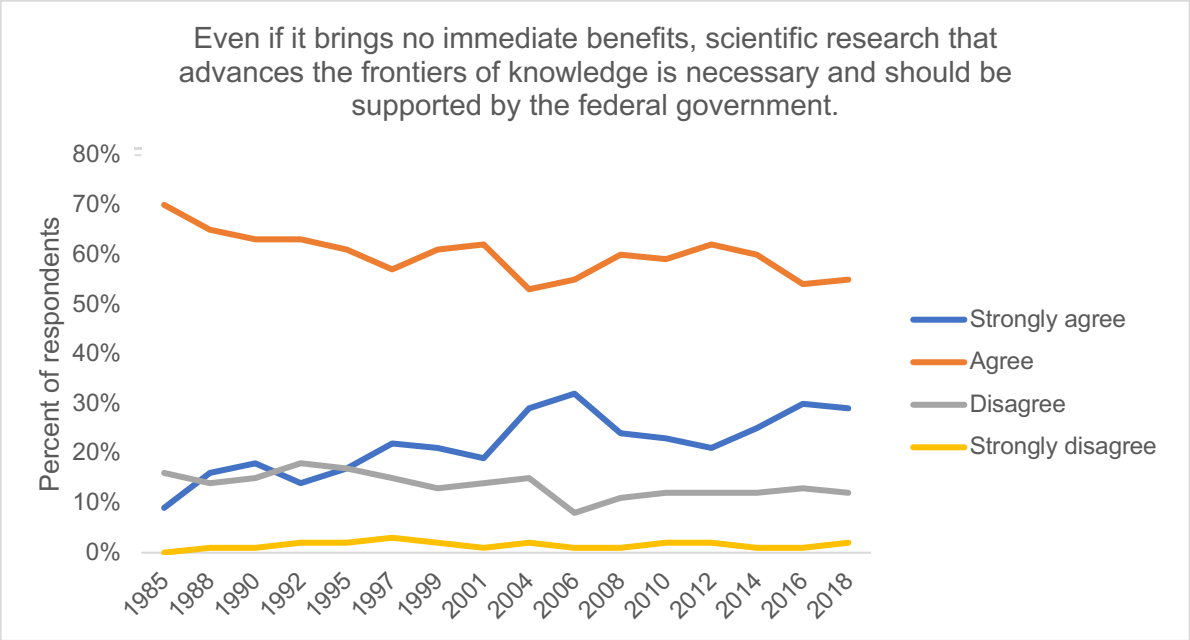



**Figure 1b.** Survey responses to the question, "Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government."
Source: GSS (2006-2018), University of Michigan, Survey of Consumer Attitudes (2004) - National Science Foundation, National Center for Science and Engineering Statistics (2019)

Within those groups, certain demographics play a role. Firstly, there is not much of a difference in opinion among those who have a bachelor's degree or less. Those with a graduate degree, however, disproportionately are more likely to "strongly agree" with support for basic science (Figure 2a). Among those with a graduate degree, 50% "strongly agree" that basic science is necessary. In other words, those who have a graduate degree (many of whom perform research) care about basic science a great deal, while others express more neutral support.

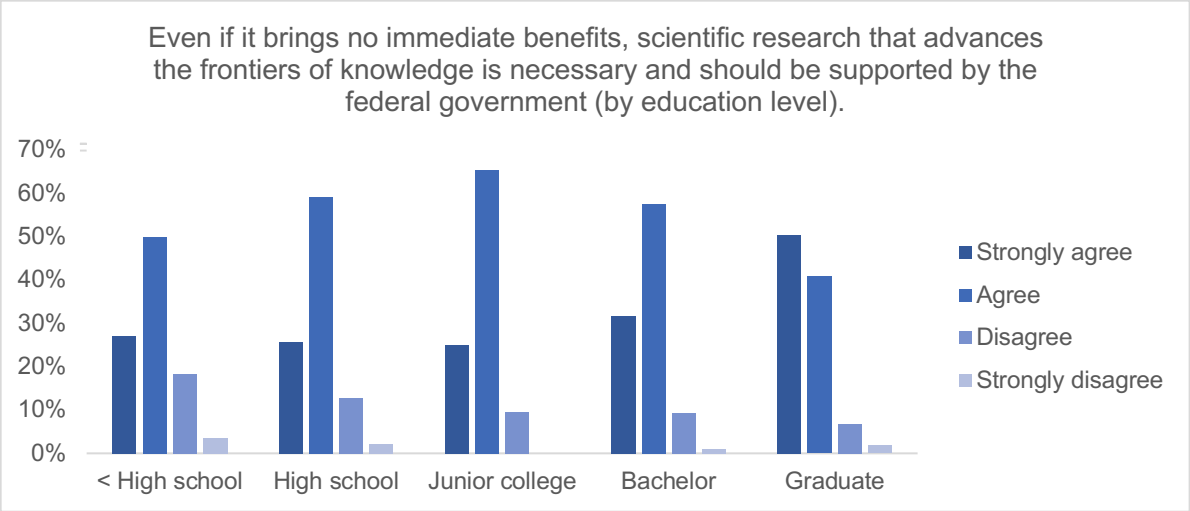



**Figure 2a.** Education level plays a role in support for basic science, but mainly only at the graduate level.
Source: GSS (2018)

Secondly, we might predict based on public sentiment that political party impacts science support. Democrats took up science as a rallying cry in the last public election, for example. However, support is still high among disparate political groups (Figure 2b). Even among Strong Republicans and Independents, for whom support dropped the most between 2006-2018, about 80% still support basic science.

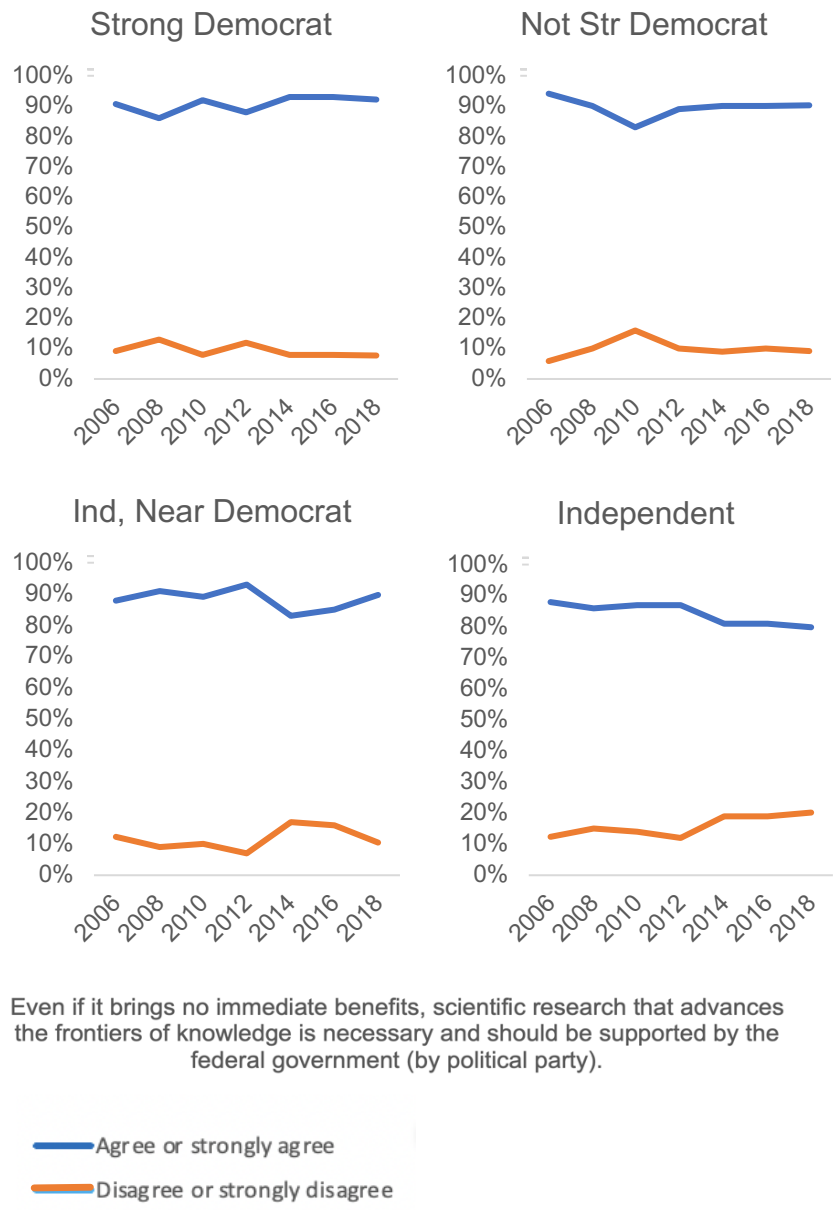



**Figure 2b.** Decreases in basic science support are only noticeable among Republicans and Independents, but even among those groups, support is near 80%.
Source: GSS (2006-2018)

These demographics indicate that basic science has strong support among self-identified Republicans and Democrats alike, despite preconceptions people might have based on modern political rhetoric. Support may certainly have shifted in the three years since the question was last asked, but by 2018, debates about science were already prevalent in the political sphere, so they may also be indicative of current support levels. Additionally, taking education level into account, it is also worth noting that scientists care the most about science. Expecting a high

level of support among a broader populace may be unrealistic. Instead, we should consider that a majority of the population expresses a more neutral support level for basic science.

Another question broadly gauging attitudes toward basic science concepts was asked by the General Social Survey in 2006: “Science is too concerned with theory and speculation.” They did not give an alternative as to what science could be focusing on, but “theory and speculation” confer the idea that science is overly conceptual and therefore not very applied. At the time, 63% said they “disagreed” or “strongly disagreed” that science is too concerned with theory and speculation, and 37% said they “agreed or strongly agreed.” There was more of a difference across educational backgrounds for this question, with those with less than a high school degree agreeing and disagreeing at roughly the same rate, while those with a graduate degree disagreeing the most (Figure 3a). Interestingly, there does not seem to be much of a notable difference across political parties for this question, apart from fewer Strong Republicans saying they strongly disagree that science is too concerned with theory and speculation (Figure 3b). This might again indicate that opinions about basic science do not differ much based on political affiliation.

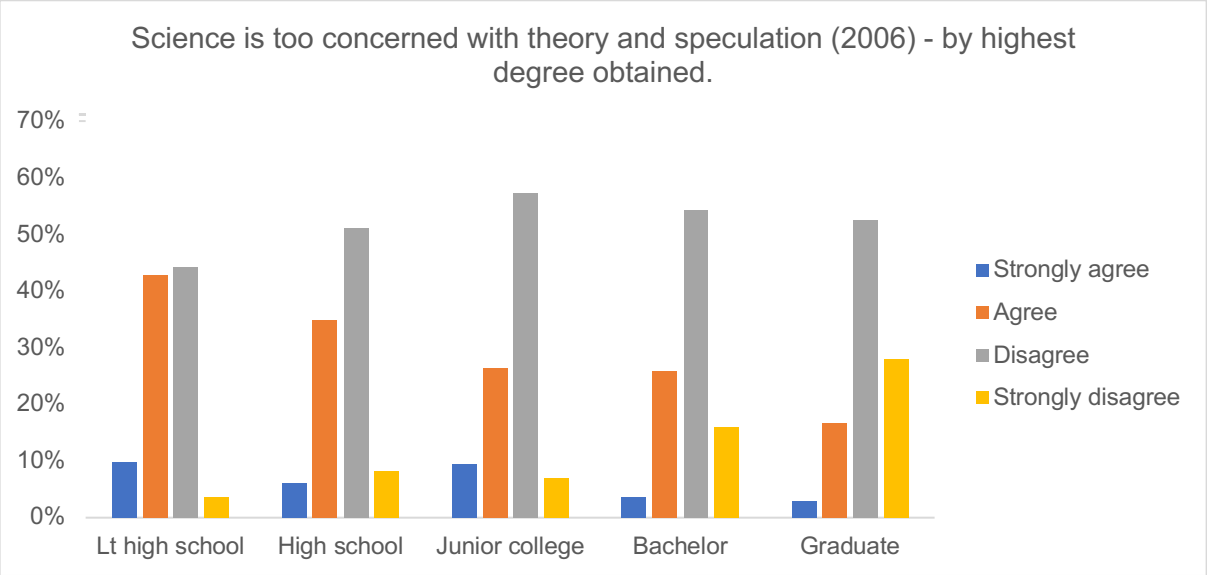



**Figure 3a.** Disagreement that science is too concerned with theory and speculation decreases with the degree level obtained.
Source: GSS (2006)

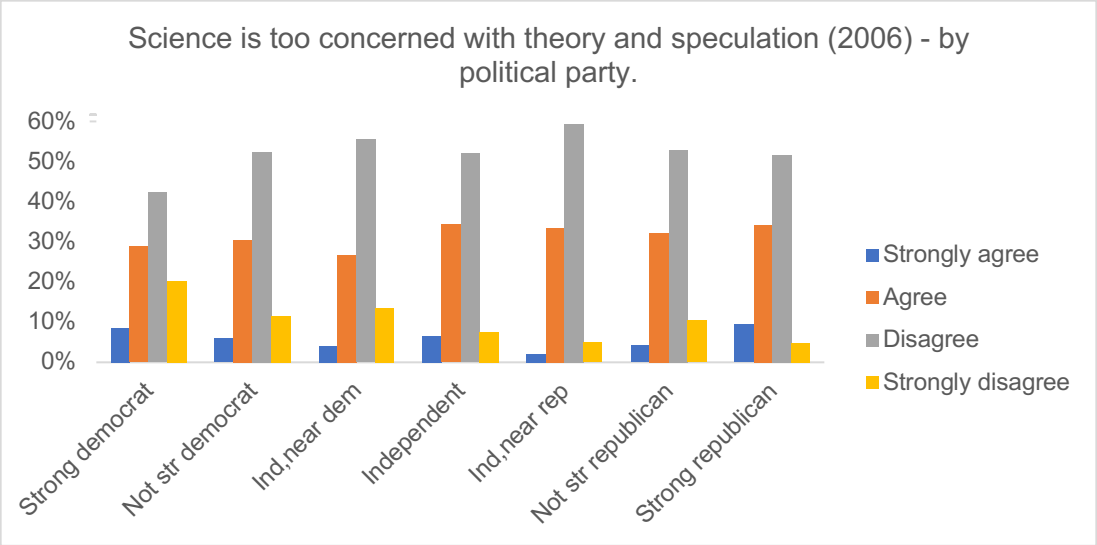



**Figure 3b.** Opinions that science is too concerned with theory and speculation are roughly the same across political parties.
Source: GSS (2006)

While these survey questions do address concepts related to basic science, we have no way of knowing what ideas respondents might have had in mind when answering the questions. Do they differentiate between basic and applied science when answering these questions? Respondents to a 2015 survey asked participants whether they had a positive, neutral, or negative association with the basic/applied science terminology, showing little difference (Table 2). Yet nearly 40% had a "neutral" association with either term, potentially indicating a lack of familiarity among many Americans with these labels. However, again, this does not indicate whether participants have roughly equivalent opinions about basic and applied science, or whether they may simply not differentiate between the two concepts. Unfortunately, there are no long-term poll trends like the basic science question from Figure 1 to compare directly. Instead, to parse this out, we can compare science support overall with support for particular kinds of science.

| | "Basic scientific research" | "Applied scientific research" |
|---|---|---|
| Positive | 58% | 54% |
| Neutral | 39% | 42% |
| Negative | 3% | 4% |
| N= 722 | | |

**Table 2.** Responses to the question, **"**Below are some words and phrases. For each, please indicate whether you have strong positive associations with the term, feel neutral about the term or have negative associations with the term."
Source: ScienceCounts, "Raising Voices for Science," 2015

Firstly, support for scientific research spending overall shows similar historical trends to support for basic science. Between 1985 and 2018, people were asked, "Are we spending too much, too little, or about the right amount on...supporting scientific research?" Although the question is framed differently from the basic science question detailed in Figure 1a, again it indicates a strong majority (86% as of 2018) support science – that is, they believe we are spending too little or the right amount (Figure 4).

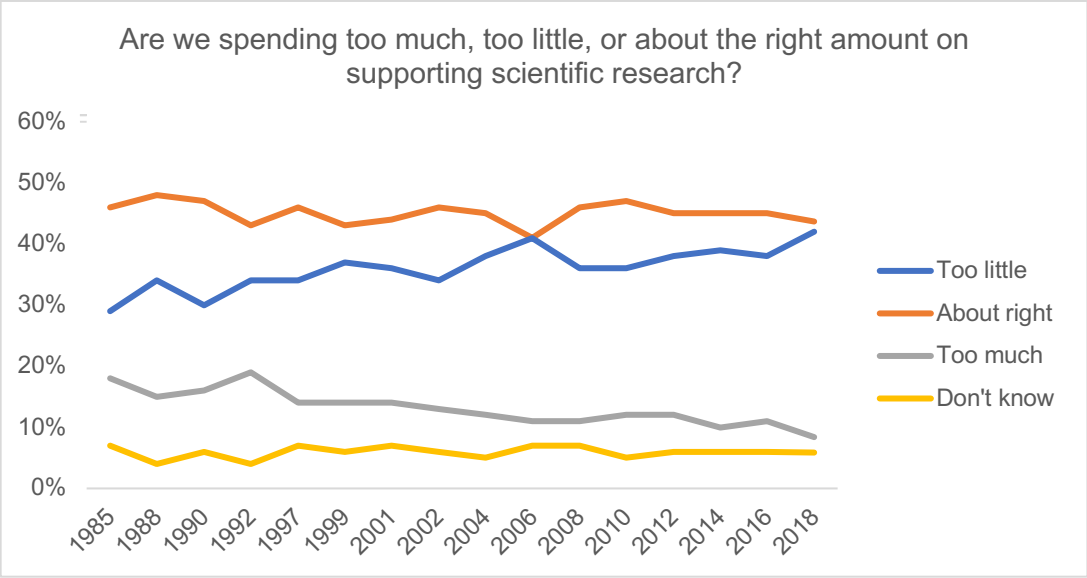



**Figure 4.** A majority of the U.S. believes we are spending too little or the right amount to support scientific research.
Source: GSS (2002-2018), National Science Foundation, National Center for Science and Engineering Statistics (2019)

This indicates that like basic science, support for science overall is high and stable over time. However, that high and stable support changes when the focus is on particular science topics. Only 68% of people said we were spending "too little" or the "right amount" on space exploration

in the same year, 2018 (Figure 5a). At the same time, only 54% had a favorable opinion of nanotechnology, saying they thought the benefits were greater than the risks (Figure 5b). In 2016, only 11% of people said that GMOs posed a low or very low risk (Figure 5c).

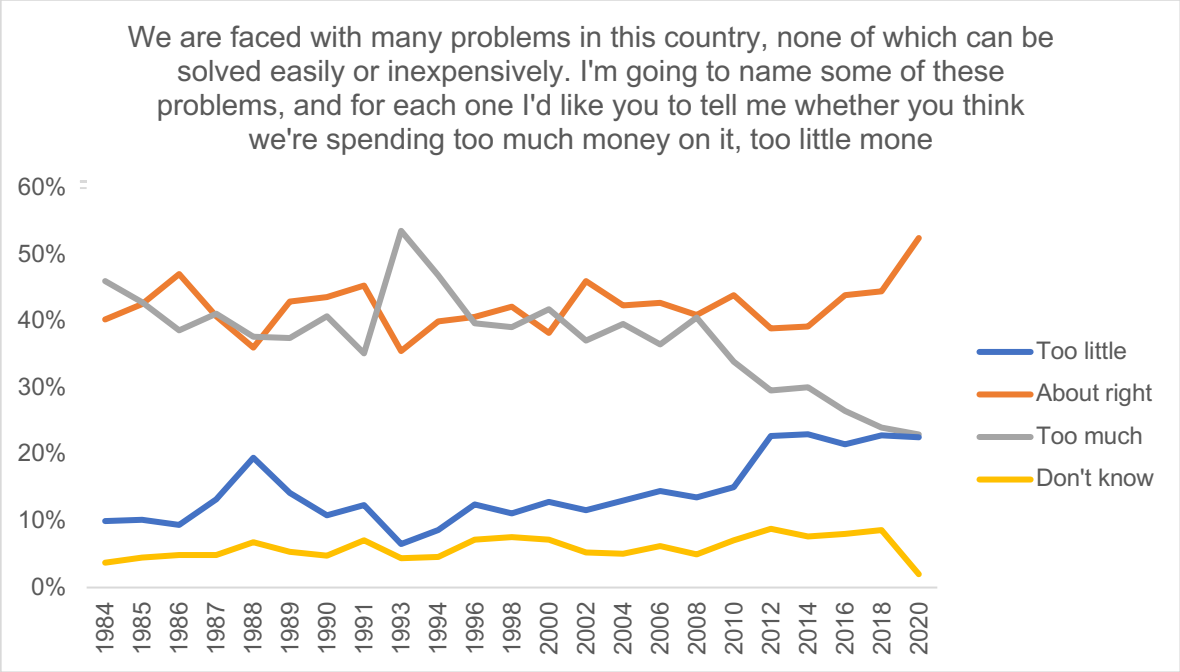



**Figure 5a.** Space exploration support has varied over the years, with most people saying we spend about right or too much, though opinions are becoming more positive over time. Source: GSS (1984-2020)

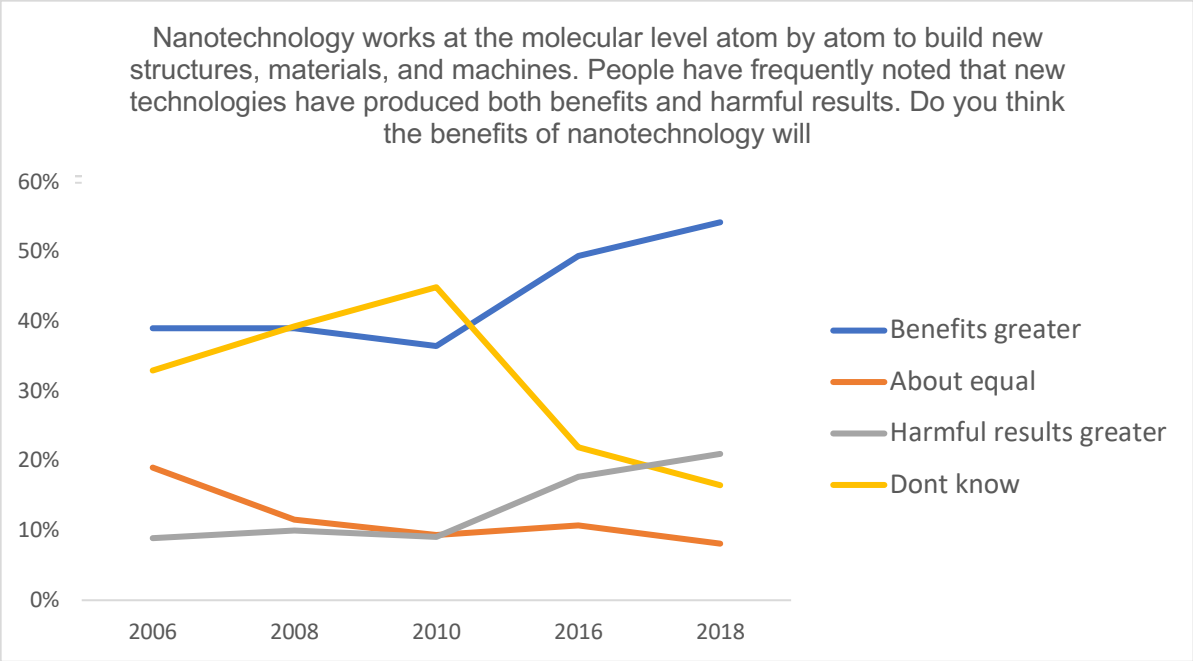



**Figure 5b.** Support for nanotechnology is increasing, with about 54% believing that benefits outweigh risks as of 2018.
Source: GSS (2006-2018)

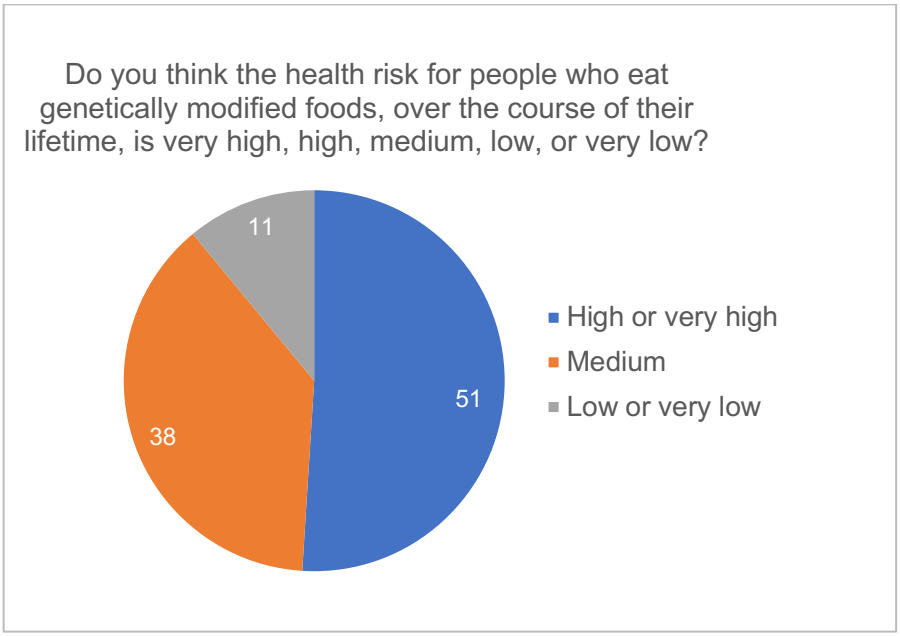



**Figure 5c.** Only 11% of people think that GMOs pose a low or very low risk to health.
Source: Pew Research Center for the People & the Press, "American Trends Panel Wave 17," 2016

Topics like GMOs, nanotechnology, and space exploration tend to be more controversial than other areas of science might be. However, these trends are worth noting. Most of the work done in these fields is probably considered to be "applied," at least from a public standpoint, because it results in products like food or other inventions or developments. There are similarly controversial topics in basic science, like the use of human embryos for general research purposes. While support for some kinds of applied science may be higher than others, similarly, support for different kinds of basic science will vary depending on the topic. The more the public learns about different fields of basic science, hypothetically, the more likely they are to develop polarized opinions about whether that science should be conducted.

This is not to say that science engagement is not worthwhile. As others have pointed out, the U.S. public gets a lot of messages about scientific, health, and other topics from experts and nonexperts alike on a daily basis, from various kinds of media as well as from friends or community members. We also know that people can have a hard time remembering where they got information. This might necessitate scientists and science organizations taking part in the constant messages.

Though basic science engagement might be worthwhile or even necessary, then, public opinion trends show several key factors that should be considered. Firstly, there may not be a problem with basic science support. Support is high and has remained consistently high since the 1980s. Strong support is increasing over time, meaning people who support basic science might feel more strongly in their support compared to in the past. However, the highest levels of strong support come from those with a graduate degree.

Secondly, political affiliation does not appear to have a strong effect on basic science support, even in more recent years (2018). Among the political groups with the lowest levels of support (Independents and Strong Republicans), a strong majority still support basic science.

Thirdly, we cannot really tell based on these data whether people differentiate "basic science" from "science" overall from "applied science." The best way to differentiate this would be qualitative interviews, where open-ended questions could be asked. This is not just a problem with the basic science questions asked here. Future work should be done to describe what concepts and ideas people hold in their minds when answering survey questions about science. Do they use context cues from other parts of the survey? Do they think of the latest science news they read? Do they conceptualize of science as a broad institution, and if so, how do they characterize and describe "science"?

In the context discussed here, we should note that those who plan to engage the public on science should also be prepared to not only increase support, but also possibly decrease support for their work. Some people may hold high opinions of "science" overall but their opinions may vary once they focus on a particular science topic. Of course, this might be happening already, with the prevalence of science information online, so scientists and science organizations should also not be discouraged from participating in the conversation.

# Part 2: Systematic Review of Basic Science Literature

We investigated to what extent public engagement with basic science is covered in journals across STEM fields and disciplines. In this report section, we introduce how we selected journals and developed search terms to cast the widest net of journals and articles to examine public engagement with basic science, and we also present our major findings.

Before we could begin the process of identifying scholarship pertaining to public engagement with basic science, we first had to define "basic science" and "public engagement."

*How to define basic science:* To start, we reviewed the websites of U.S. mission federal agencies to find their definitions of basic science (Table 3). The intent was to create a list of keywords that encompassed basic science. Some websites did not present a clear definition, but the following is what we found:

| Basic Science Funding or Mission Agency | Basic Science Keywords |
|---|---|
| **National Science Foundation** | General knowledge, experimental, theoretical |
| **U.S. Department of Agriculture** | No clear definition found |
| **U.S. Department of Energy** | Fundamental, new understanding |
| **U.S. Department of Defense** | New knowledge, scientific capital (adapted from statement by Vannevar Bush |
| **U.S. Department of Health and Human Services** | No clear definition found |
| **National Institute of Health** | Fundamental research, new knowledge |
| **NASA** | Basic understanding that underlies space exploration applications |
| **Association of the American Medical Colleges** | Fundamental or bench research, foundation of knowledge |
| **U.S. Department of Commerce** | No clear definition found |

**Table 3.** U.S. federal agencies' definitions of basic science.

*How to define public engagement:* For the purposes of this review, we drew on previous research investigating public engagement to develop our working definition as well as relevant keywords. Our definition follows what is proposed in Scheufele et al. (2021), by defining public engagement as "processes and initiatives focused on enabling public participation in the responsible innovation and development of new technologies, including the management and

assessment of technical risks" (p. 1). The key point of our focus therefore was on further defining terms and phrases centered on processes, initiatives, and participation.

## Journal Selection

To examine public engagement with basic science, it is crucial to capture the largest net of basic science publications as possible. Therefore, we curated a large scale of journals and corresponding article information from four STEM research fields which are the focus area of The Kavli Foundation: neuroscience, physics, nanoscience, and chemistry as well as from a STEM field with a focus on human behavior: psychology. We used Web of Science, one of the largest databases that cover journal articles for each field, to collect all the journals and article information.

Figure 6 shows the user interface of the Web of Science website. Researchers are able to select the field on the left side bar "Select Categories" (e.g., Neurosciences). Researchers are also able to download all the journals indexed at Web of Science from the Journal Citation Reports for a specific field (e.g., 272 journals in Neurosciences, see Figure 7). The UW-Madison has a collaboration with the Web of Science database, which allowed out team to collect all the article related information (e.g., article title, abstracts, published date, funding agency, keywords) for each article in a journal since a journal's earliest published year. Table 4 describes the total number of journals and article abstracts we collected for our analysis, which focus on all articles that were published in the past five years (2015-2019).

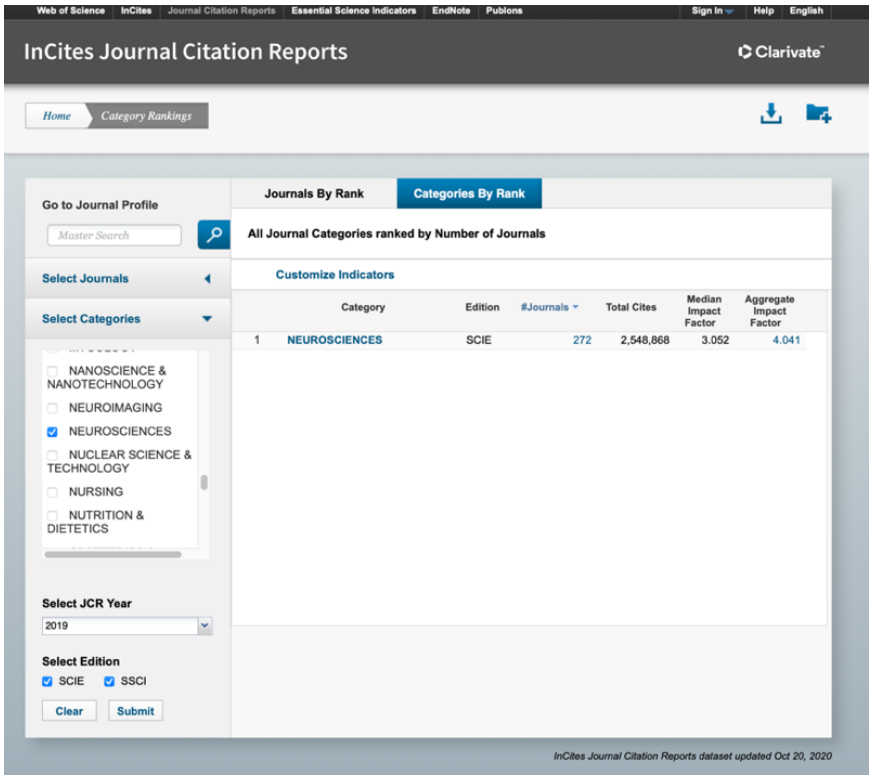
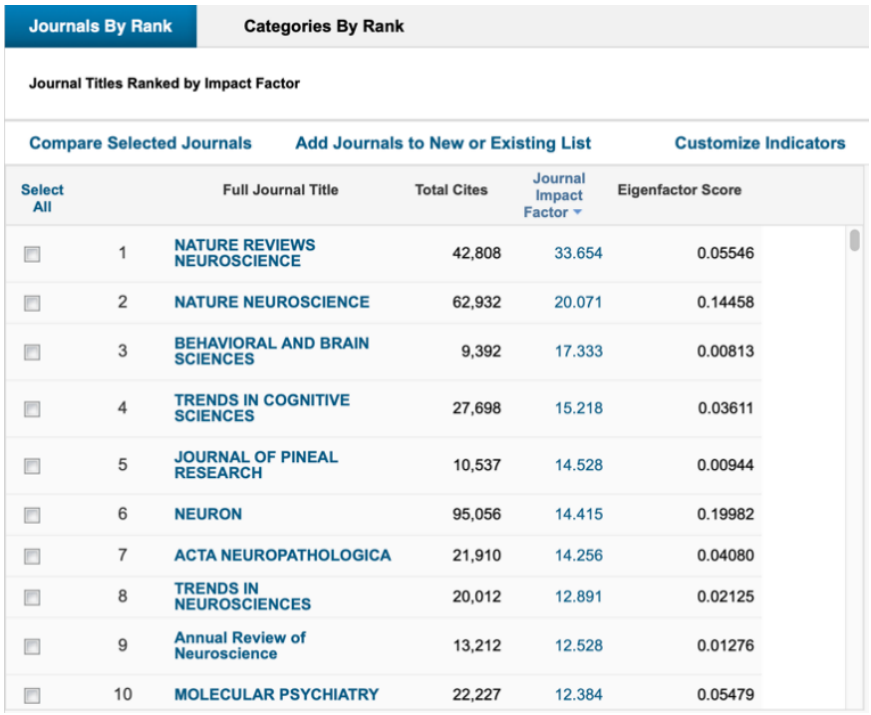



**Figure 6.** Web of Science user interface.



Journals By Rank | Categories By Rank

Journal Titles Ranked by Impact Factor

Compare Selected Journals | Add Journals to New or Existing List | Customize Indicators

| Select All | | Full Journal Title | Total Cites | Journal Impact Factor | Eigenfactor Score |
|---|---|---|---|---|---|
| ☐ | 1 | NATURE REVIEWS NEUROSCIENCE | 42,808 | 33.654 | 0.05546 |
| ☐ | 2 | NATURE NEUROSCIENCE | 62,932 | 20.071 | 0.14458 |
| ☐ | 3 | BEHAVIORAL AND BRAIN SCIENCES | 9,392 | 17.333 | 0.00813 |
| ☐ | 4 | TRENDS IN COGNITIVE SCIENCES | 27,698 | 15.218 | 0.03611 |
| ☐ | 5 | JOURNAL OF PINEAL RESEARCH | 10,537 | 14.528 | 0.00944 |
| ☐ | 6 | NEURON | 95,056 | 14.415 | 0.19982 |
| ☐ | 7 | ACTA NEUROPATHOLOGICA | 21,910 | 14.256 | 0.04080 |
| ☐ | 8 | TRENDS IN NEUROSCIENCES | 20,012 | 12.891 | 0.02125 |
| ☐ | 9 | Annual Review of Neuroscience | 13,212 | 12.528 | 0.01276 |
| ☐ | 10 | MOLECULAR PSYCHIATRY | 22,227 | 12.384 | 0.05479 |

**Figure 7.** A snapshot of journals in neurosciences.

The Web of Science database allows us to collect a variety of useful journal article related information in an Excel spreadsheet format such as the article abstract and title, the authors and affiliations, keywords and subjects of an article, and the funding agencies. We used the article abstract and the title as our unit of analysis to identify potential articles that discuss public engagement with basic science.

| Field of Interest | Number of Journals Studied | Number of Article Abstracts Collected |
|---|---|---|
| **Chemistry** | 578 | 758,565 |
| **Physics** | 469 | 404,880 |
| **Neuroscience** | 272 | 223,831 |
| **Nano** | 103 | 30,989 |
| **Astronomy & Astrophysics** | 68 | 98,727 |
| **Psychology** | 642 | 232,971 |
| | N= 2,132 | N= 1,540,963 |

**Table 4.** Description of our collected dataset (2015-2019).

## Search Terms Development and Automatic Detection

After we collected all the journal abstracts and titles, we developed an inclusive list of search terms that are related to public engagement. These search terms were used in the automatic detection (described in the next part) for potential journal articles that cover public engagement. We decided to only develop search terms related to public engagement due to the difficulty of developing a reliable set of keywords for basic science/discovery science/fundamental research. These terms did not appear frequently, and our search for keywords based on previous definitions were too broad, returning a significant number of false positives. Our approach was therefore to use manual content analysis to determine if an article with a public engagement focus also focuses on basic science research. We discuss this approach in more detail in the following sections.

Drawing from frameworks that appear in the public engagement and science communication literature (Fung, 2006; Rowe and Frewer, 2005; Scheufele et al., 2021), our search terms for public engagement fall into one of three major groups. Search terms under Group 1 are related to the *communication process*; search terms under Group 2 are related to the *communication modality*; search terms under Group 3 are related to the different *audiences and stakeholders* in public engagement. These three groups capture public engagement from its process to modality and to the audiences. We included the variants of each search term to capture all the scenarios that this term could be used in an article: e.g., for the search term "participate," we also include ['participate,' 'participation,' 'participated,' 'participates,' and 'participating']. Table 5 presents a final list of the search words in each group. In addition to the keywords for each group, we also identified a number key phrases related to public engagement practices. These key phrases serve as a separate category due to their occurrence indicating a strong signal that the article has a public engagement focus.

It is important to note that our search term development was a process of several rounds of refinement using domain knowledge from science communication scholars on the team. For instance, in Group 2 (i.e., modality), our initial search terms also included "interview." However, after we pulled all the article abstracts that contain the word "interview" and took a reading of a random sample of abstracts, we found that interview is often used in these articles as a research method instead of a way to engage the public with the basic science topic. Therefore, we did not include interview in our final search term list.

| Group | Related Search Terms |
|---|---|
| **Group 1: search terms related to communication process** | participate, engage, communicate, consult, deliberate, involve, empower, co-creation, persuade and their variants |
| **Group 2: search terms related to communication modality** | meeting, townhall, museum, zoo, festival, crowdsourcing, workshop, outreach, and their variants |
| **Group 3: search terms related to the communication audience** | public, citizen, consumer, client, participant, stakeholder, politician, administrator, representative, student, NGO, policy, civic and their variants |

| | |
|---|---|
| **Key Phrases related to public engagement** | public discourse, citizen discourse, public debate, citizen debate, public understanding, public acceptance, consensus conference, deliberative poll, citizen science, informal learning, citizen panel, focus group, public opinion, non-governmental organization |

**Table 5.** Search terms related to public engagement.

*Automatic Detection of Potential Articles on Public Engagement.* We wrote computer programming scripts to identify potential journal articles that discuss public engagement practices through finding if our search terms occur in both the article title and/or the abstract. For an abstract, it is selected if it contains the search terms from both Group 1 (communication processes) and Group 3 (communication audience) or search terms from Group 2 (communication modality) or from the Key Phrases. For a title, it is selected if it contains any search terms under Group 2 or the Key Phrases or contains search terms from both Group 1 and Group 3 (with distance within 3 words). After this automatic detection process, Table 6 presented the number of abstracts/titles that were identified from each field.

| Field of Interest | Number of Abstracts/Titles Identified | Number of Titles Identified |
|---|---|---|
| **Chemistry** | 2,288 | 174 |
| **Physics** | 837 | 52 |
| **Neuroscience** | 2,595 | 40 |
| **Nano** | 0 | 0 |
| **Astronomy & Astrophysics** | 290 | 20 |
| **Psychology** | 16,138 | 414 |
| | n = 22,148 | n = 700 |

**Table 6**. Number of abstracts and titles identified using our search terms.

Our results indicate that titles and/or abstracts that reference public engagement appear very infrequently, with fewer than 1 in 10,000 articles (≤.01%) in chemistry, physics, neuroscience, nanoscience, and astronomy & physics returning a positive match. However, articles appearing in psychology journals were more likely to include matches, which is due to the field's focus on understanding human behavior.

# Qualitative Content Analyses

We conducted a qualitative content analysis for the 700 potential journal article abstracts whose titles were identified using our search terms to examine whether they discuss public engagement, and if it was focused on basic science. We chose to narrow our sample for manual

content analysis to only those with keywords and/or phrases appearing in the title to determine how often false positives occur, as well as provide a sample size conducive to manual coding. Moreover, we concluded that a keyword and/or search string match appearing in the article title would be a more direct signal for it focuses on public engagement with science. Drawing from Scheufele et al. (2021), we defined an article content that covers public engagement as those that refer specifically to "*processes and initiatives focused on enabling public participation […].*" As previously mentioned, we were able to identify those articles that focused on basic science mainly by determining what they are not: applied scientific research. If a clear application was identified in the abstract, the article was coded as not basic research. If the article did discuss basic science concepts as they relate to public engagement (e.g., understand the process of science as it relates to a particular field) then the article was coded as relevant to public engagement with basic science.

While article titles were used to narrow our sample, our unit of analysis for the manual coding was the article abstract. We coded each article into three values: "0", the article abstract does not refer to public engagement, "2", the article abstract refers to public engagement with basic science, and "1", examples where public engagement focus is vague as well as unclear whether it focused on basic science concepts. Table 7 presents examples for each coding case. As we can see from the first example, even though the article abstract contains our communication modality keyword, "crowdsourcing," and was thus identified in our automatic detection as a potential candidate, we can see that the abstract describes crowdsourcing as a research method for recruiting participants in the experimental research rather than as a public engagement exercise to engage citizens with a basic science topic.

| Coded Values | Examples |
|---|---|
| **0: the article abstract does not refer to public engagement at all** | "Crowdsourcing data collection from research participants recruited from online labor markets is now common in cognitive science. We review who is in the crowd and who can be reached by the average laboratory. We discuss reproducibility and review some recent methodological innovations for online experiments. We consider the design of research studies and arising ethical issues. We review how to code experiments for the web, what is known about video and audio presentation, and the measurement of reaction times. We close with comments about the high levels of experience of many participants and an emerging tragedy of the commons." |
| **2: the article abstract refers to public engagement** | "In order to make science more appealing to students, it is imperative that a real-world approach to the principles of chemistry be taught in the classroom enabling students to see the applicability of chemistry to their everyday lives. In this laboratory activity, students were asked to bring in everyday food items that contain food dyes. The students then synthesized the FD&C dyes yellow 5 and yellow 6. The dyes were then run, along with their food items, on a TLC plate in order to determine what dyes were present in the foods and drinks they consume." |

**Table 7**. Manual content analyses examples.

## Public Engagement with Basic Science in STEM Journals

Four researchers on the team conducted manual content analysis of these 700 potential articles. We found that 70% of these articles (n = 489) returned false positives, while 30% (n = 211) had a clear public engagement focus. Further analysis revealed that among the 30% of articles that have a clear public engagement focus, only 20% (n = 43) included a focus on concepts related to basic science.

The result shows that even with the large sample of journals and corresponding articles we have curated, and an inclusive list of search terms we developed to detect articles on public engagement, there are very few articles in the STEM-specific journals that discuss public engagement generally, or basic science concepts specifically. Moreover, given the number of false positives that appear in our sub-sample, the number of articles on public engagement may be even smaller.

Nonetheless, we do find several interesting trends among those articles that have a clear public engagement focus as well as a focus on basic science research. Taking a close read of the 43 articles annotated as clearly on public engagement with basic science, we found that many of the articles that discuss public engagement appear in chemistry journals. In total, 14 articles appeared in the *Journal of Chemical Education*. These articles were mostly focused on understanding and interest in basic science concepts. Other examples of engagement come from astronomy and astrophysics and document ways in which citizen science (e.g., crowdsourcing of images) help researchers observe and document different phenomena. We provide a curated overview of a selected number of the articles that fit our criteria for public engagement with basic science (see Appendix A).

To conclude, based on our systematic assessment, we suggest several opportunities for moving forward with public engagement on basic science. First, very little research exists on public engagement broadly, and basic science specifically, in the discipline specific STEM journals. This is not to say that this research exists outside of the peer-reviewed literature (e.g., conference proceedings), but it does not indicate a clear research literature focused on this topic that stands on the best available science in communication and public engagement. As most of the research that we identified that focused both of public engagement with basic science appears in educational and informal science learning contexts, specific outcomes of such processes focus on fostering curiosity and interest, specifically with pursuing a STEM career. Moving forward, the scientific community needs to be much more transparent with participants and the broader public about their motivations and goals for public engagement with basic science. Simply building support for or excitement about science that might produce applications with disproportionate impacts on vulnerable populations is shortsighted at best and unethical at worst. Public engagement efforts therefore need to consider the outcomes of public engagement activities, and not only how these activities lead to changes in attitude, opinion, and behavior among the public, but also among the scientists and the work that they do.

# Part 3: Case Studies: Nanotechnology and Biotechnology

In this section, we present three case studies regarding the public engagement context of nanotechnology, biotechnology, and chemistry. Each case studies briefly describes the historical context of public engagement, examines what type of public engagement happened, and concludes with what the science communication community can draw from regarding public engagement with basic science.

## Nanotechnology

Nanotechnology is an umbrella term for our ability to manipulate matter at the scale of individual atoms and molecules (i.e., modifications at 1-100 nanometers). It's noteworthy not so much as a feat of incredible technical precision, but rather for the transformative potential it unleashes, especially as disparate disciplines converge at the nanoscale. The ways in which powerful nanotechnology, biotechnology, cognitive science, and information technology intersect is so important for governance and regulation that this domain is referred to as "NBIC" technology (Roco & Bainbridge, 2003).

NBIC technologies are often described as having three characteristics. First, they emerge in new interdisciplinary areas that most non-expert publics did not encounter in schools or universities. Second, they are characterized by rapid bench to bedside transitions from basic research to applications entering the consumer end market. Finally, many of the questions these applications raise are "wicked" in nature (Rittel & Webber, 1973), i.e., they don't have simple technical answers that can be provided by science. Instead, they raise ethical, moral, political, or other societal questions that can only be answered through political debate and value trade-offs (D. A. Scheufele, 2014).

### *Historical Context*

When nanotechnology emerged as an enabling technology, industry and academia had just completed their first inventories of what had gone wrong with the way they had communicated about GMOs. For nanotech, BASF and other large chemical companies had invested more than 90% of their R&D budget in nano-related applications and were worried about replicating the communication debacle surrounding GMOs. As a result, industry focused much of their trademarking, product marketing and end market messaging on a "nano is nature" frame and the idea of "bio-inspired products," especially in markets like Germany that had been openly hostile to GMOs. Examples include trademarks based on plant names, like Degussa's *Lotus Effect* imagery evoking comparisons to nature, for instance in Henkel's *Nanit Active dental sealant,* and green and brown colors for packaging and advertising. Even academic publications by industry labs emphasize nano connections. Felix Mueller and his colleagues at various Degussa labs, for example, describe the Lotus Effect (Mueller, Michel, Schlicht, Tietze, & Winter, 2007)

To our knowledge, there is no published study systematically evaluating how successful these campaigns were in countering potential consumer concerns. As a result, it is impossible to determine if “nano is nature” framing prevented consumer backlash against nanotechnology, especially in heavily anti-GMO countries such as Germany, or if communication strategy did not matter because there was never any real concern. But the lack of widespread controversy is certainly consistent with what one would expect based on existing framing research and the industry approach to the terminology they used in product rollouts. In the end, nanotechnology enjoyed lots of funding and investment worldwide, healthy markets, and broad consumer acceptance (D. A. Scheufele, Corley, Shih, Dalrymple, & Ho, 2009).

A second difference between how industry and academia treated GMOs and nanotechnology is their approach to public engagement. In the early 2000s, Alan Leshner, then CEO of the American Association for the Advancement of Science, the largest U.S. general scientific association, rattled scientists’ cages by calling for broad public engagement. “[G]iven the uncertainties in science,” Leshner argued, “the best science-based strategy is not always as clear as we would like and as many in our community might claim” (Leshner, 2003). As a result, he called for an honest bi-directional dialogue about both the perils and the pitfalls of science.

***What type of public engagement happened?***

When nanotechnology emerged as a field, many in the academic and policy community took Leshner’s call seriously. Early efforts developed into what some commentators have described as a “growing political commitment at the highest levels to giving citizens more of a voice in the decisions that affect their lives, and to engaging citizens in making government more responsive and accountable” (Cornwall, 2008, p. 11). Public meetings as a tool for formal citizen engagement were an integral part of a 2000 U.K. House of Lords report (U.K. House of Lords, 2000) that recommended making the direct dialogue with the public a mandatory and integral part of policy processes, and also the 2003 U.S. Nanotechnology Research and Development Act, which mandated “convening of regular and ongoing public discussions, through mechanisms such as citizens’ panels, consensus conferences, and educational events” ("21st Century Nanotechnology Research and Development Act," 2003).

These efforts were partially motivated by the desire to anticipate reactions among members of the public in response to potentially controversial technologies early and to “avoid unjustifiably inhibiting innovation, stigmatizing new technologies, or creating trade barriers” (Holdren, Sunstein, & Siddiqui, 2011, p. 1). This echoes conclusions of a 2008 National Research Council consensus report that showed that public participation in (environmental) assessment and decision have the potential to not just improve perceptions of legitimacy but also the quality of decisions (National Research Council, 2008).

It important to keep in mind that public engagement on nanotechnology did not start out in response to adverse events or public outcry. Many efforts to engage emerged while most members of the public in Europe, Asia, and the United States were still unaware of and certainly unopposed to nanotechnology and its potential applications, even after some 1,500 nano-enabled products had been introduced to the consumer market (Bainbridge, 2002; Beck, 2006; Burri & Bellucci, 2008; D. A. Scheufele, 2006).

And efforts to engage focused not just on the science itself, but also on some of the societal questions surrounding it. The U.S. National Science Foundation (NSF), for example, funded two Centers for Nanotechnology in Society at a total of $25 million over ten years to study the how to build better connections between the science that was being developed and the different public stakeholders that were potentially affected. In collaboration with museums and science centers, NSF also helped create the Nanoscale Informal Science Education Network (NISE Net), also funded at over $25 million, to develop museum exhibits, visitor activities, and kits to be sent to smaller regional museums to enable engagement with broad cross-sections of the population. There are too many other efforts that were funded and that explored new ways of engaging with the public to list them all. All of them tackled ethical issues, regulatory questions, or even explored novel ways of engaging the public (Anderson, Kim, Scheufele, Brossard, & Xenos, 2013; Batt, 2008; Corley, Kim, & Scheufele, 2012; Corley, Kim, & Scheufele, 2016; Guston & Sarewitz, 2002; Hamlett & Cobb, 2006; Kleinman, Delborne, & Anderson, 2011). In other words, some of the difficult conversations that had to happen did happen with universities, museums, and other trusted intermediaries serving as conveners.

# Biotechnology

Recent breakthroughs in genome editing using CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) provide probably the most real-time trial run of some of the communication dynamics around emerging technology and highlight the need for meaningful public engagement.

### *Historical Context*

Even in the early days of genome editing, stakeholders have claimed that emerging basic science (and its applications) are inextricably linked to the need for decision making that relies on the best available science, but ultimately is driven by value-based considerations and societal tradeoffs. At a Pacific Grove, CA meeting in February 1975, an international group of scientists decided that strict controls should be placed on the use of recombinant DNA, i.e., transplanting genes from one organism into another (Berg, Baltimore, Brenner, Roblin, & Singer, 1975).

“The warnings from this group – often referred to as the Asilomar conference – were echoed in a report to the U.S. Senate Committee on Human Resources’ Subcommittee on Health and Scientific Research … which argued that it was “increasingly important to society that the serious problems which arise at the interface between science and society be carefully identified, and that mechanisms and models be devised, for the solution of these problems” … For U.S. Senator Jacob Javits those solutions were inherently political ones, since, as he put it in in 1976, a ‘scientist is no more trained to decide finally the moral and political implications of his or her work than the public – and its elected representatives – is trained to decide finally on scientific methodologies.’” (D. A. Scheufele, 2014)

The advent of early tools for editing the genome of plants quickly triggered public controversy, most notably a *Nature* correspondence that raised concerns about Monarch larvae being

adversely affected in their growth and survival rates by a specific variant of genetically modified pest-resistant *Bt* corn (Losey, Rayor, & Carter, 1999).

The report triggered an intense academic debate, including criticism from some of Losey's own colleagues at Cornell, who raised methodological concerns. This technical debate among a group of specialized scientists was largely glossed over by the news outlets covering the *Nature* piece. Instead, *USA Today*'s front page made the sweeping announcement that "Engineered corn kills butterflies" (Fackelmann, 1999, p. 1A), and the *Washington Post* pitted "biotech" researchers against the monarch butterfly – the "'Bambi' of insects." (Weiss, 1999, p. A3)

Following some of these scientific debates, efforts to engage publics and policymakers focused largely on applications and their anticipated risks and benefits (National Research Council, 2015). Conceptually, stakeholders from nonprofits, academia, and different communities of practice typically pushed for some combination of storytelling, information sharing, and honest, transparent dialogues among researchers and publics. In reality, however, many efforts to engage with different publics were implicitly driven by concerns of consumer backlash against applications of basic science in once it entered the marketplace (Dietram A. Scheufele, Krause, Freiling, & Brossard, 2021).

This same thinking spilled over into early days of discovery surrounding CRISPR. Concerns quickly emerged that CRISPR applications might encounter public opposition of the kind that genetically modified organisms (GMOs) triggered when they first entered the marketplace. And public engagement early on was seen as a strategic tool: "Without increased consumer acceptance – likely achieved by improved methods of education and public engagement – CRISPR agricultural applications may face the same regulations and challenges of traditional GMOs, hampering CRISPR's contribution toward feeding a growing global population" (Shew, Nalley, Snell, Nayga, & Dixon, 2018).

To some degree this was unsurprising. CRISPR was surrounded by discussions about its legal, ethical, moral, and political implications from its earliest stages. CRISPR co-inventor Jennifer Doudna at UC-Berkeley was a driving force behind this push for a broad look at this new technology and its societal implications, even before the first concrete applications were available (Jones, 2017). It is particularly telling that some of the earliest voices calling for a broad societal debate were also pioneers of CRISPR who stood to gain both financially and in terms of academic fame from the technology moving to market. In addition, surveys have indicated for years now growing concern about these technologies "*blurring the lines between God and man*" and being "*in conflict with religious and moral views*" (Akin et al., 2017).

***What type of public engagement happened?***

As a result, the U.K. Royal Society, the U.S. National Academies, the German Academy of Science Leopoldina, the Chinese Academy of Sciences, and the French Academy of Sciences held a first international summit to discuss the future of genome editing in 2015 in Washington, D.C. Subsequently, members of all academies contributed to a consensus report for the U.S. National Academies outlining possible paths forward for basic research and applications. Interestingly, the report called explicitly for broad public engagement in any applications that went beyond currently approved techniques (National Academies of Sciences, 2017). A second

global summit in Hong Kong in October 2018 coincided with news about twins being born in China whose genome had been edited for resistance to HIV.

At first glance, editing the human genome for resistance to HIV seems like an obvious target. For decades, researchers all over the world have been looking for a permanent cure to HIV. Similarly, Tay-Sachs, Huntington's, Sickle Cell, and other genetically inherited diseases have had devastating effects on patients and their families. So why would we not use all available tools to help these patients? The answer is as simple as it is complicated: solutions have unintended consequences, many of them difficult to predict. What about off-target effects, i.e., unintended interactions of what seems like a simply genetic edit with other parts of the genome? In 2016, researchers reported editing the genome of beetles in order to remove a horn on their forehead, only to accidentally grow a third eye (Busey, Zattara, & Moczek, 2016). Or what about untended consequences of human genome editing that might be used by patients for "off label" uses. What if a cure for Tay-Sachs could also lead to increased cognitive functioning? Would parents be tempted to edit healthy unborn children to get the side benefits that might get their kids admitted to Harvard or Oxford 18 years down the road?

Ethicists have long flagged this as one of the truly "wicked" problems of emerging science: "We are already approaching a stage at which ethical issues are emerging, one upon another, at a rate that outstrips our capacity to think through and appropriately respond" (Khushf, 2006).

Many seemingly beneficial applications of genome editing as a basic science might therefore lead to unintended negative side effects – perceived or real. Public opinion research reinforces this idea. In the United States, for instance, there are wide gaps in how much respondents trust in university and industry scientists, depending on their religious backgrounds or levels of knowledge. But regardless of how much they oppose or support emerging science, recent research has shown that there is a broad desire across different publics to be involved in the conversations about how these new technologies are being rolled out (D. A. Scheufele et al., 2017).

As a result, broad public engagement with different stakeholders will be crucial in order to identify potential side effects before they materialize, or to even start asking the right questions. Or as Harvard science and technology studies scholar Sheila Jasanoff and her colleagues put it: *"The initial framing of an issue shapes the analysis of alternatives, whether scientific, ethical, or political. This is one reason inclusivity at the agenda-setting table is so valuable: it helps to ensure that important perspectives are not left out at the start, only to surface after possibly unjust judgments and decisions have been taken"* (Jasanoff, Hurlbut, & Saha, 2015).

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# Appendix

Selected articles on public engagement with basic science.

| Title | Journal | Year | Abstract |
|---|---|---|---|
| **Bringing Organic Chemistry to the Public: Structure and Scent in a Science Museum** | Journal of Chemical Education | 2017 | We have developed an organic-chemistry-themed museum exhibit that is appropriate for all ages. The goal of the exhibit is to introduce the general public to the concept of molecular structure by relating structure to scent. |
| **Polymer Day: Outreach Experiments for High School Students** | Journal of Chemical Education | 2017 | We present a collection of hands-on experiments that collectively teach precollege students fundamental concepts of polymer synthesis and characterization. These interactive experiments are performed annually as part of an all-day outreach event for high school students that can inform the development of ongoing polymer education efforts in a university setting. The Advanced Polymer Synthesis experiment aims to introduce broad concepts of polymer synthesis. Techniques such as ring-opening polymerization are explained and demonstrated. The Block Polymer Micellization experiment extends this idea to block polymers for drug delivery applications. Students are taught the idea of self-assembly and prepare micelles to encapsulate beta-carotene in water with flash nanoprecipitation. In terms of materials characterization, the vast physical properties space of polymers is explored. The Happy Sad Spheres experiment provides an interactive demonstration of the glass transition temperature, while the Polymer Swelling/Rheology experiment features the interesting properties of cross-linked and entangled polymers. Evaluation surveys showed positive feedback from students in learning polymer concepts through this program. Overall, the simple principles taught by these outreach experiments can be easily incorporated into modern laboratory curricula with broad implications for disseminating public knowledge and promoting continued interest in polymer science and engineering. |
| **Using Polymer Semiconductors and a 3-in-1 Plastic Electronics STEM Education Kit to Engage Students in Hands-On Polymer Inquiry Activities** | Journal of Chemical Education | 2017 | To improve polymer education for 9-12 and undergraduate students, a plastic electronics laboratory kit using polymer semiconductors has been developed. The three-module kit and curriculum use polymer semiconductors to provide hands-on inquiry activities with overlapping themes of electrical conductivity, light emission, and light-harvesting solar energy conversion. Many of these themes are critical to contemporary polymer molecular electronics research. The kit includes modules to synthesize and evaluate the electrical properties of conductive colloidal polyaniline (PAni), to construct a polymer light emitting diode using poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEH-PPV), and to build a polymer solar cell using MEH-PPV and nanoparticulate TiO2. Designed initially for high school science classrooms, the activities developed also meet new ACS undergraduate education requirements for macromolecular, supramolecular, and nanoscale systems in the curriculum and can be used in undergraduate teaching laboratories. The modules and kit have also been implemented in professional development workshops for training 9-12 science educators to help integrate the activities into their classrooms. |

| | | | |
|---|---|---|---|
| **Writing Without Ink: A Mechanically and Photochemically Responsive PDMS Polymer for Science Outreach** | Journal of Chemical Education | 2017 | An easy-to-implement science outreach demonstration featuring a mechanically and photochemically color-changing polymer is described. The active polymeric material is a filled poly(dimethylsiloxane) (PDMS) elastomer that is covalently functionalized with spiropyran (SP), which is both a photochemical and mechanochemical switch. The material can be reversibly changed from colorless to dark purple by exposing it to light from a blue laser pointer or providing a mechanical stimulus such as hitting the polymer with a hammer or dragging a blunt object across the surface. The keynote demonstration is a PDMS chemical-drawing board that allows children literally to "write without ink" using a laser pointer or a blunt stylus. Collectively, these demonstrations are suitable for various student groups and encompass concepts in polymer and materials chemistry, photochemistry, and mechanochemistry. This demonstration has been successfully employed dozens of times in multiple universities across North America. |
| **Experimenting with a Visible Copper-Aluminum Displacement Reaction in Agar Gel and Observing Copper Crystal Growth Patterns to Engage Student Interest and Inquiry** | Journal of Chemical Education | 2016 | The reaction process of copper aluminum displacement in agar gel was observed at the microscopic level with a stereomicroscope; pine like branches of copper crystals growing from aluminum surface into gel at a constant rate were observed. Students were asked to make hypotheses on the pattern formation and design new research approaches to prove their hypotheses. Results of the experiments designed by students well proved the existence of microcells in reaction system, which caused continuous growth of copper branches. The whole experimental teaching process motivated students by stimulating their interest and enthusiasm. |
| **Engaging Students in Real-World Chemistry through Synthesis and Confirmation of Azo Dyes via Thin Layer Chromatography to Determine the Dyes Present in Everyday Foods and Beverages** | Journal of Chemical Education | 2017 | In order to make science more appealing to students, it is imperative that a real-world approach to the principles of chemistry be taught in the classroom enabling students to see the applicability of chemistry to their everyday lives. In this laboratory activity, students were asked to bring in everyday food items that contain food dyes. The students then synthesized the FD&C dyes yellow 5 and yellow 6. The dyes were then run, along with their food items, on a TLC plate in order to determine what dyes were present in the foods and drinks they consume. |

| | | | |
|---|---|---|---|
| **ConfChem Conference on Flipped Classroom: Improving Student Engagement in Organic Chemistry Using the Inverted Classroom Model** | Journal of Chemical Education | 2015 | Improving student engagement in STEM (science, technology, engineering, and mathematics) courses generally, and organic chemistry specifically, has long been a goal for educators. Recently educators at all academic levels have been exploring the "inverted classroom" or "flipped classroom" pedagogical model for improving student engagement in subjects spanning the fields from liberal arts to business studies to science and technology. This learner-centered pedagogy, in which course content is delivered outside the classroom, allows class time to be more productively used for higher-level engaging activities, such as collaborative and problem: based learning through instructor-led applications of the material delivered outside of class. The techniques used and the technology employed to deliver an inverted two-semester organic chemistry classroom at Rowan College at Gloucester County along with preliminary student performance data versus the traditional lecture classroom format are presented. This communication summarizes one of the invited papers to the ConfChem online conference Flipped Classroom, held from May 9 to June 12, 2014, and hosted by the ACS DivCHED Committee on Computers in Chemical Education (CCCE). |
| **Using a Deliberation of Energy Policy as an Educational Tool in a Nonmajors Chemistry Course** | Journal of Chemical Education | 2016 | A central goal of nonmajors chemistry courses is to instill within students the sense that chemistry does not occur in a vacuum but rather permeates everyday life. To encourage students to consider chemistry within the broader context of society and public policy, a week-long module in a survey course for nonmajors was designed to connect scientific principles and energy policy. This module featured a deliberative discussion to facilitate students' evaluation and consideration of multiple viewpoints, rigorously examining different perspectives, trade-offs, benefits, and values represented in multiple alternatives. Our results demonstrate that this approach was highly impactful, resulting in several significant positive outcomes, including a deeper awareness of the. connection between chemistry and other disciplines, an increased level of understanding and confidence in their knowledge, and a greater sense of urgency regarding energy policy. |
| **Chemistry and Art in a Bag: An Easy-To-Implement Outreach Activity Making and Painting with a Copper-Based Pigment** | Journal of Chemical Education | 2016 | An easy-to-implement outreach chemistry activity showing the synthesis, isolation, and use of a copper-based pigment, malachite, with three paint binders is described. This activity is adapted from a traditional chemistry laboratory experiment and can be performed in a sandwich bag using plastic utensils within a 15 min time frame. Student group size is kept at five students maximum, allowing interaction between a large number of students over the course of a 3 h outreach event. This Science Technology Engineering Arts and Mathematics (STEAM) experiment combining chemistry with art has the advantage of demonstrating a chemical reaction by the observation of a precipitate and evolution of a gas, which most students find highly intriguing. Discussions about chemical reactions, physical and chemical changes observed, and the interplay of chemistry and art took place between the authors and the students, who were highly engaged. |
| **Collaboration and Near-Peer Mentoring as a Platform for Sustainable Science Education Outreach** | Journal of Chemical Education | 2015 | Decreased funding for middle and high school education has resulted in reduced classroom time, which, when coupled with an increased focus on standardized testing, has decreased the exposure of many middle school students to hands-on science education. To help address these challenges, we developed an integrated outreach program, spanning grades 6-12, designed to engage students by bringing students to the University of Oregon to perform hands-on laboratory experiments. Initially developed to supplement science education lost to state-mandated furlough days, the programmatic design can be applied readily in other contexts including afterschool, weekend, or summer programs. The outreach activities and scaffolding rely heavily on near-peer mentoring; which provides a visible pathway for younger students to envision themselves as future scientists while also providing mentoring and leadership opportunities for high school, undergraduate, and graduate students. The use of near-peer mentoring is also critically important for the program's sustainability because it enables a more efficient allocation of graduate student and faculty time. In the first 2.5 years, over 450 middle school students have participated in the program and student feedback shows that students are engaged and excited about the outreach activities. |

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| **Chemistry Science Investigation: Dognapping Workshop, An Outreach Program Designed to Introduce Students to Science through a Hands-On Mystery** | Journal of Chemical Education | 2017 | The Chemistry Science Investigation: Dognapping Workshop was designed to (i) target and inspire fourth grade students to view themselves as Junior Scientists before their career decisions are solidified; (ii) enable hands-on experience in fundamental scientific concepts; (iii) increase public interaction with science, technology, engineering, and mathematical personnel by providing face-to-face opportunities; (iv) give teachers a pathway forward for scientific resources; (v) meet the New Mexico K-5 Science Benchmark Performance Standards; (vi) most importantly, ensure everyone has fun! For this workshop, the students are told they will be going to see a Chemistry Magic Show, but the performance is stopped when the Chemistry Dog is reportedly stolen. The students first clear their names using a series of interactive stations and then apply a number of science experiments to solve the mystery. This report describes the workshop in detail, which is suitable for large (similar to 100 students per day) audiences but has flexibility to be modified for much smaller groups. An identical survey was given three times (before, immediately after, and 2 months after the workshop) to determine the impact on the students' perception of science and scientists as well as determine the effectiveness in relaying scientific concepts through retention time. Survey responses indicate that scientific information pertaining to the workshop is retained for up to 2 months. |
| **Reflections on "YouTestTube.com": An Online Video-Sharing Platform to Engage Students with Chemistry Laboratory Classes** | Journal of Chemical Education | 2016 | This paper describes the construction and development of YouTestTube.com, a YouTube clone website to facilitate video-sharing, social networking, and reflections of chemistry laboratory classes for year one students within the School of Biomedical Sciences at Ulster University. The practice was first introduced in the 2008/09 academic year and has developed until the present time. We reflect on our findings with regard to the production and sharing of short student-generated video documentaries on laboratory experiments, and attendant social networking. We found that students enjoyed the process of viewing, rating, and commenting upon colleagues' videos but that social networking did not happen spontaneously or organically. Students did find that learning and networking happened effectively when working in small groups to produce the final version of the video. The use of some of the videos as peer-generated learning objects was reported to be useful in helping engage year one, semester one students in their early days in tertiary education. |
| **The Moon Zoo citizen science project: Preliminary results for the Apollo 17 landing site** | Icarus | 2016 | We derived the optimal data reduction steps and settings of the existing Moon Zoo crater data to agree with the expert census. Further, the regolith depth and crater degradation states derived from the data are also found to be in broad agreement with other estimates for the Apollo 17 region. Our study supports the validity of this citizen science project but also recommends improvements in key elements of the data acquisition planning and production. (C) 2016 The Authors. Published by Elsevier Inc. |
| **Junocam: Juno's Outreach Camera** | Space Science Reviews | 2017 | Junocam is a wide-angle camera designed to capture the unique polar perspective of Jupiter offered by Juno's polar orbit. Junocam's four-color images include the best spatial resolution ever acquired of Jupiter's cloudtops. Junocam will look for convective clouds and lightning in thunderstorms and derive the heights of the clouds. Junocam will support Juno's radiometer experiment by identifying any unusual atmospheric conditions such as hotspots. Junocam is on the spacecraft explicitly to reach out to the public and share the excitement of space exploration. The public is an essential part of our virtual team: amateur astronomers will supply ground-based images for use in planning, the public will weigh in on which images to acquire, and the amateur image processing community will help process the data. |
| **"It Was Like I Had Found My Tribe": Influence of a Neuroscience Outreach** | Neuroscientist | 2017 | Engaging young people with science is essential to ensuring a scientifically literate society. Furthermore, it is important to enable access to a variety of sciences during adolescence, when individuals are making decisions about their future educational and career paths. The Brain Bee Challenge (BBC) is a quiz-based international neuroscience outreach program for high school students. We wished to determine what influence exposure to the scientific research environment had on the highest |

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| | | | achievers' later choices in education, their career expectations, and their perspectives toward science. Semistructured interviews were carried out with seven of the past winners of the New Zealand National BBC finals. Analysis involved thematic |

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