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Public Perceptions of Scientific Uncertainty and Media Reporting of Reproducibility and Replication in Science

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I. Introduction

I.a. *Uncertainty, reproducibility, and replicability in science*

Uncertainty is intrinsic to science and necessary to communicate when sharing scientific results, as scientific uncertainties shape how stakeholders interpret and act on scientific information in decision-making. The exact effects of uncertainty, however, depend on multiple factors. How individuals understand and act on uncertainty varies depending on the particular science issue, the source and media they receive the information from, how those sources present the information, and how the information interacts with the recipients' values, goals, and experiences.

Within scientific research, two features of the scientific method that researchers use to manage uncertainty are reproducibility and replicability. Reproducibility is rerunning analyses from another study using the same data and methods to try to achieve the same results as the original study. Replicability attempts to achieve similar findings as an earlier study using different data and analyses. Reproducibility can give evidence of previous findings' reliability, in that the results can be reliably produced by others. Replicability can provide insight into results' validity by adding to the body of evidence that a particular phenomenon exists.

Reproducibility and replication (R&R) are part of how scientific knowledge differs from other sources of information. They can help produce greater certainty in the information, as scientific information solidifies through collecting evidence of the reliability and validity of results over time and across settings through R&R of previous research. R&R can also introduce uncertainty, however, when new studies do not reproduce previous findings. Recent findings that studies in some science fields, such as psychology, are not easily reproduced have introduced uncertainty over how reliable and valid those findings are (and how reliable and valid the R&R studies themselves are) and triggered discussion over whether there is a "crisis" in science or in particular science fields. To better understand this uncertainty, however, researchers continue collecting information through R&R studies to weigh whether the original findings or new findings have more evidence in their favor.

I.b. *Overview of this report — public perceptions & media coverage*

Given the importance of uncertainty in scientific information and communication of that information, as well as the role of R&R in managing (and sometimes adding to) uncertainty, understanding public views of science requires understanding views of both uncertainty and R&R. This paper summarizes two areas of research related to these factors. Part 1 reviews the literature on how the public perceives scientific uncertainty, how different factors can shape those perceptions, and ways to effectively communicate uncertainty. Part 2 describes media coverage of R&R in science in general and of R&R failures as indicative of a "crisis." Crisis, here, captures discussion focused on the failure to replicate/reproduce scientific results and on the need for R&R as timely, systemic issues that researchers have to address in scientific research. This description combines analyses of online- and print-media sources, Twitter discourse, and top Google Search results and YouTube videos focused on R&R in science.

The literature review in Part 1 indicates that how people view scientific uncertainty depends on characteristics of the content and the recipient of that content, mirroring the larger body of research on risk and science communication. Uncertainty can increase risk perceptions of an issue – especially when paired with a negative frame – but can also increase the credibility of the information and of the scientists involved. It can spur people to action to address uncertainty – especially when paired with a positive frame – but also can offer justification for people to dismiss scientific information that conflicts with their other held values and beliefs. The modern media environment plays mixed roles in these outcomes, increasing the chances of seeing conflicting information while also offering ways for accurate uncertainty information to reach people who otherwise might be less exposed or open to that information. Overall, people appear to expect uncertainty in science. There are ways to communicate uncertainty more effectively, however, to avoid creating additional, unnecessary, or misleading sources of uncertainty or confusion. The end of Part 1 (Section II.c.) offers recommendations for communicating uncertainty and for correcting misperceptions when necessary.

Results of Part 2 indicate that media coverage of R&R is relatively small compared to other science topics and is dominated by academic or science-focused sources, suggesting that issues of R&R are not especially salient in the larger public. Coverage often focuses on particular science fields or on R&R as part of the scientific process, and recently coverage is shifting to discourse on what steps should or are being taken to increase R&R in science.

This paper ends with discussion of the implications of these results for understanding how people view scientific uncertainty, especially in the context of R&R in science.

II. Part 1: Public Perceptions of Scientific Uncertainty

A small body of research examines how scientific uncertainty shapes opinion formation and decision-making in the public. For clarity, this overview sorts the factors shaping how people perceive uncertainty into 1) the presentation of uncertainty, both within and across articles and mediums, and 2) how recipients process information, depending on motivations, ability, and values. The two types of factors interact to create an array of interpretations and reactions among the public concerning scientific uncertainty. This review focuses on broader patterns in how those factors and interactions affect public views to understand the views of the U.S. public in general and how to communicate issues related to R&R to a general public.

II.a. *The presentation of uncertainty*

In the literature on uncertainty, uncertainty generally appears through caveats (hedges) and through inclusion of multiple viewpoints from the scientific community. Such viewpoints add uncertainty either through conflicting interpretations or by giving caveats in interpretations of scientific results. In addition to these features, literature on uncertainty often focuses on risk perceptions related to uncertainty. How a story frames uncertainty relative to risk, either through negative or positive frames, shapes perceptions of that information. The modern media environment affects presentation as well, as context and social cues, such as related stories linked to an article or user-generated comments, add additional frames and information that can shape who receives and interprets the uncertainty information. This section focuses on these factors in turn: presentation of uncertainty within and across articles, and presentation within and across mediums.

II.a.i Presentation of uncertainty within & across news stories

II.a.i.1. Hedges

Hedges (also called powerless language) include using words such as “might,” “in some cases,” and “possibly” and are key to communicating scientific information accurately – partly, however, because they communicate uncertainty in scientific results. Research on hedges in persuasive communication, such as editorials and legal arguments, found that hedges lower perceived authoritativeness of the speaker (Hosman, 1989) and increase negative views of the messages (Blankenship & Holtgraves, 2016). Research on hedges in science communication, however, finds that hedges can increase credibility of the information or of sources associated with the information (Durik, Britt, Reynolds, & Storey, 2008; Jensen, 2008; Ratcliff, Jensen, Christy, Crossley, & Krakow, 2018; Winter, Krämer, Rösner, & Neubaum, 2014). In one study, the most hedge-free version of scientific information was least effective in gaining credibility among readers (Winter et al., 2014). Additional research found that hedges in coverage of cancer research – reporting study limitations and caveats given by the cancer researchers – increased perceived trustworthiness of the scientists and journalists involved (Jensen, 2008), while a replication study found that hedges did not affect views of scientists but did increase credibility of journalists associated with a story (Ratcliff et al., 2018). Although the findings vary on exact effects in terms of whether it is perceived credibility of the story, the scientists, or the journalists involved that increases, overall they suggest that people differently perceive scientific information than other types of information, expecting and accepting more uncertainty in scientific information.

II.a.i.2. Conflict versus caveats

Research suggests, however, that hedges are more effective when researchers use them to discuss the results of their own work than when scientists criticize or add caveats to the work of other researchers (Jensen, 2008; Jensen et al., 2017). This distinction in who provides the caveats can be more important than the caveats themselves (Jensen et al., 2017). These findings align with research on the effect of one- versus two-sided information in which the two-sided information includes conflict-based uncertainty from scientists disagreeing. When two-sided information includes scientists contradicting each other or adding caveats to another researcher's work rather than to their own, the information can increase perceived tentativeness of scientific results (Chang, 2015; Flemming, Feinkohl, Cress, & Kimmerle, 2015, 2017; Kortenkamp & Basten, 2015; Nagler, 2014), decrease perceived credibility of the associated scientists and journalists (Chang, 2015; Kortenkamp & Basten, 2015), decrease support for the research or related technology (Chang, 2015; Flemming et al., 2017), and increase "fatalism" in views toward preventing or alleviating sources of risk and uncertainty (Jensen et al., 2017).

In these studies, uncertainty arose through exposure across several news articles containing different and contradictory information (Chang, 2015; Flemming et al., 2015, 2017; Nagler, 2014) or within one article containing hedges from a researcher criticizing or contradicting another researcher's statements (Jensen et al., 2017; Kortenkamp & Basten, 2015). When all researchers in the story provide both pro- and contra-arguments, however, or all share caveats for understanding research results, such two-sided aspects to a story can increase the perceived credibility of the scientists (Mayweg-Paus & Jucks, 2017), or at least not decrease credibility the way conflict-focused two-sided information can (Kortenkamp & Basten, 2015).

The effects of conflict-focused two-sided information, however, can vary across studies. Uncertainty stemming from disagreement between experts on the effects of hypothetical flooding from climate change made participants see flooding as more likely (less uncertain), for example, than did uncertainty stemming from climate models (Patt, 2007). Another study found that adding uncertainty through caveats from particular scientists versus uncertainty from conflict between scientists did not differentially affect participants' views of uncertainty or risk from nanotechnology except for among participants who were more deferent to the authority of scientists. Those who were more deferent had higher risk perceptions when they read articles with conflict-based uncertainty (Binder, Hillback, & Brossard, 2016).

As the Binder, Hillback, & Brossard (2016) study highlights, the mixture of findings regarding the effects of two-sided information and conflict is likely partly due to how the particular science issue and the characteristics of recipients of that information affect perceptions and reactions to uncertainty. Some recipients often prefer two-sided information despite the increased uncertainty it creates, especially recipients with a higher need for cognition who are motivated to work through and understand information (Winter & Krämer, 2012). Additionally, a study comparing effects of conflicting information in articles on two science issues – dioxin in sewage versus wolf reintroduction – illustrates well how the effects of uncertainty depend on the particular issue. Conflict between researchers' interpretations of results decreased recipients' certainty in their own prior beliefs and increased perceived credibility of scientists involved in the dioxin article but had the opposite effects on certainty and credibility in the wolf article (Jensen & Hurley, 2012).[1]

II.a.i.3. Positive and negative frames

Negative frames can increase perceived uncertainty in scientific information (Kimmerle, Flemming, Feinkohl, & Cress, 2014), perhaps by making people more attentive to uncertainty, but can also increase tolerance for conflicting information and change intentions to act on uncertainty. In the literature on one- versus two-sided information, for example, one study found

[1] These mixed results could be an example of differences in how much people rely on scientific information to understand an issue. For example, dioxin in sewage can have personal health effects that would be difficult to see or understand without some scientific information. People could therefore rely more on scientific information and expertise when forming opinions on how serious the issue is and what to do about it, even with uncertainty in that information. On the other hand, wolf reintroduction is an issue in which scientific information on the impacts of wolves on ecosystems, for example, might not be the salient information people use when forming opinions on the issue. Instead, views of wildness, the role of humans in nature, and other value-driven concerns could play a larger role. These views could lead people to rely even more heavily on, or have greater certainty in, their own beliefs on the issue when they see pieces of scientific information that conflict each other. This discussion will reemerge in the section on how recipient values and views of different science issues shape their reactions to uncertainty around those issues (section II.b.ii).

that people generally preferred vague statements from scientists in agreement over more precise statements from scientists in conflict (Smithson, 1999). When framing was negative, however, preferences flipped and people wanted precise information, even with conflict-based uncertainty, rather than vague, agreed-upon scientific interpretations (Smithson, 1999). This difference could reflect people's general tendency to become more or less risk-averse depending on whether the frame of information is of gains or losses, respectively (Kahneman & Tversky, 1984; Tversky & Kahneman, 1974, 1981). When faced with what seems like a sure loss, for example, people tend to become more risk-seeking to avoid that loss (Kahneman & Tversky, 1984). Being more open to conflict-based uncertainty when faced with negative frames, then, could indicate lower aversion to risk in information and lead to preferences for having more precise information, even if it contains conflicting statements.

Negative frames combined with uncertainty information can also make people lower their intentions to behave in ways that would address the uncertainty – such as taking actions to avoid risks of climate change (Morton, Rabinovich, Marshall, & Bretschneider, 2011). This effect on behavioral intentions could be from negative frames 1) increasing feelings of powerlessness to act in the face of uncertainty or 2) as the loss/gains research (Kahneman & Tverksy, 1984) indicates, decreasing motivation to act due to higher risk tolerance in the face of loss. In contrast, uncertainty combined with positive frames can produce stronger intentions to act to address uncertainty. In those cases, perceived self-efficacy can mediate feelings of uncertainty related to behaviors that could mitigate uncertain outcomes, such as effects of climate change (Morton et al., 2011). These results highlight that it is often not the uncertainty itself but the way it appears and the feelings that presentation elicits that shape people's opinions and actions concerning the information.

II.a.ii. <u>Presentation of uncertainty within and across news mediums</u>

As fewer science journalists publish in traditional print outlets and more alternative sources for scientific information emerge through online and social media platforms (Brossard, 2013; Brossard & Scheufele, 2013; Brumfiel, 2009; Newman, Fletcher, Kalogeropoulos, Levy, & Nielsen, 2017; H. P. Peters, Dunwoody, Allgaier, Lo, & Brossard, 2014), a plethora of outlets and context cues affect how people receive and perceive uncertainty in scientific information, with both negative and positive effects.

II.a.ii.1. Detriments of the media environment: exposure to conflicting or inaccurate stories

One way the modern media environment can increase perceptions of uncertainty in a negative or misleading way is by increasing the likelihood that people will receive conflicting information (Dunwoody, 1999; Purcell, Brenner, & Rainie, 2012) or misinformation (Garrett, Weeks, & Neo, 2016). Traditional coverage of science can provide conflicting takes on the same scientific study, but because online media sources increase individuals' access to a wider array of outlets, they can increase the chance that someone sees multiple, possibly contradictory versions of the same story (Dunwoody, 1999).

Additionally, information on online platforms comes surrounded by context cues that shape perceptions of the story beyond any effects caused by the content of article itself. Comments, for example, can contain contradictory or misleading information and can create a negative frame around an article. Uncivil comments following an otherwise neutral article on nanotechnology increased risk perceptions of nanotechnology for those individuals who were already leaning toward not supporting the technology, further polarizing audiences (Anderson, Brossard, Scheufele, Xenos, & Ladwig, 2014). This effect could have occurred from comments increasing perceptions of uncertainty around the information, leading people who were already predisposed to disagree with the information to view the article as less reliable. That uncertainty, then, could provide those individuals with rationale for more heavily relying on their prior views of the science issue than on information provided in the article itself (see footnote 1, pg. 9 for more on this process). Both the uncivil comments and the potential for increased exposure to contradictory articles in online environments could mean that even stories that avoid conflicting information or negative frames end up surrounded by conflict-producing cues that can increase perceptions of uncertainty and decrease perceptions of scientific credibility.

II.a.ii.2. Benefits of the media environment: exposure to accurate, trusted sources

Exposure to multiple different sources and cues for information on a science issue, however, can also provide outlets for effective and accurate communication of scientific uncertainty. Three interrelated ways it can do this are through 1) reducing inaccurate views of uncertainty, 2) making information more attractive or approachable, and 3) helping science information reach people who would otherwise not be open recipients to such information.

Reducing inaccurate views. Through many of the same features that help spread misinformation, online and social media can also offer outlets for alleviating misperceptions. Research on reducing misperceptions of science issues finds that context cues on social media can provide corrections that help people more accurately understand uncertainty in issues. This research focuses on science issues for which public views of scientific consensus do not match the actual high levels of scientific consensus – such as consensus on the safety of consuming genetically modified (GM) foods, drivers of climate change, or health effects of vaccines. In experiments, when a story with misinformation on GM foods or vaccines on Facebook was followed by a "related stories" link to articles with more accurate information on the issue, readers had significantly reduced perceptions of the uncertainty present in those fields (Bode & Vraga, 2015). Expert sources, such as the CDC, can also effectively correct misperceptions through comments or posts following posts that contain misinformation. One experiment modeling Twitter posts found that when the CDC tweeted a refutation to a tweet that incorrectly attributed the spread of the Zika virus to the release of GM mosquitoes, viewers of both tweets had significantly reduced misperceptions, especially viewers who were most likely to initially believe the misinformation (Vraga & Bode, 2017). Such tweets did not affecting the credibility of the CDC (Vraga & Bode, 2017), suggesting they could be an effective way to alleviate perceptions of uncertainty created through misperceptions.

Misperceptions are often notoriously hard to undo, however, especially when they align with strongly held values and worldviews. In a worst-case scenario, corrections can back-fire, with those who most strongly believe false information reinforcing their beliefs in the face of corrections (see, for examples, Hart & Nisbet, 2011; Nyhan & Reifler, 2010; Nyhan, Reifler, Richey, & Freed, 2014). Although meta-analyses indicate that back-fire effects do not occur for most issues (Walter & Murphy, 2018), there are several ways to ensure that corrections will be more likely to work in the intended direction. Corrections are most effective when they offer a coherent story to fill the gap left by misperceptions or misinformation. The correction has to be as satisfactory in explaining the situation or issue as the misinformation was (Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012; Seifert, 2002; Walter & Murphy, 2018) and can be more effective if it also explains why the original, misinformed, claim emerged (Seifert, 2002). Evidence suggests that corrections should include a direct rebuttal of the misinformation (Walter & Murphy, 2018), similar to what the Vraga & Bode (2015; 2017) studies found, and that highlighting scientific consensus can be effective for some issues (Lewandowsky, Gignac, & Vaughan, 2012). Corrections are less likely to back-fire if they align with or do not contradict respondents' worldviews, especially the worldviews that made the misinformation attractive and easily understandable (Lewandowsky, Ecker, et al., 2012). Lewandowsky, Ecker, Seifert, Schwarz, & Cook (2012) and Walter & Murphy (2018) offer more detailed overviews on processes and recommendations for communicating corrections.

Making information approachable. Online media in particular also offer cues that can make it less likely that individuals' held values and worldviews will lead to them avoid certain information. User-generated context cues such as shares and likes can increase the likelihood that individuals will attend to information, even if that information does not align with their prior beliefs on the issue (Messing & Westwood, 2012). These social cues help users bypass other more ideologically or value-based cues triggered by an article itself when deciding whether to pay attention to the story. This could create opportunities for accurate information to shape opinions on the science issue, possibly in ways less affected by value-based motivated reasoning in which people preferentially weigh or discount information that matches or conflicts with held-beliefs, respectively (see section III.b).

Opportunities for greater reach. Because of the opportunities described above, social cues and the multiple pathways that information moves through in the modern media environment then make it possible for information to reach people who would otherwise be less receptive to scientific information or less trusting of scientific sources. For example, a recent study of the impact of the National Academies of Sciences, Engineering, and Medicine's (NASEM) consensus report on the effects of genetically-engineered crops (National Academies of Sciences, 2017) found that after the report's release and its movement through news outlets and social media, public perceptions of GMOs moved more in line with the findings of the report, seeing less risk but not more or less benefit (Howell et al., forthcoming). More interesting for understanding the role of the media environment in shaping perceptions, however, was that risk perceptions around GMOs reduced most among people who were least likely to be the regular choir for such information. Those least likely to find scientific reports reliable or believe that scientists are credible sources of information on GMOs had the greatest reduction in risk perception coinciding with the NASEM report's release (Howell et al., forthcoming). The results suggest that the scientific consensus information could have reached those individuals through other outlets that they found more credible or trustworthy than they would a scientific report from a committee of researchers.

The findings above do not give a simple picture of how scientific information's movement across mediums affect perceptions of uncertainty, and that movement currently is unpredictable and impossible to control. The findings highlight, however, that the web of outlets, speakers, and context cues do not necessarily only create or reinforce inaccurate pictures of uncertainty in science. They also provide opportunities for accurate information to reach both interested audiences and audiences who might not have been receptive to that information in other contexts. As more and more individuals rely on online and social media for information in general and on science in particular (Newman et al., 2017; Shearer & Gottfried, 2017), this mixture of effects will continue to play an increasingly important role in understanding public views of scientific uncertainty.

II.b. *How people process (uncertainty) information*

As the previous section on presentation of uncertainty illustrates, uncertainty's effects depend on how information interacts with the values and experiences of the person receiving it. Those characteristics fall into two categories: 1) motivation and ability to find and process information on scientific uncertainty, and 2) value-based pathways that affect openness to and subsequent processing of information. The body of literature on how these factors shape perceptions of scientific uncertainty is small. The findings overlap, however, with the larger body of research on how motivation, ability, and value-based processing shape opinion formation, which this overview also draws from. Because focusing on individual characteristics is less useful on its own for understanding how the general U.S. public views scientific uncertainty, these sections focus only on individual characteristics for which data is available on the prevalence of those characteristics in the U.S. population.

II.b.i. <u>Public understanding of scientific studies</u>

Perceived and actual ability, which can overlap with experience and knowledge, shape the extent to which someone can and will work to understand and act on information (Budescu, Broomell, & Por, 2009; Einsiedel & Thorne, 1999; Fung, Griffin, & Dunwoody, 2018; Griffin, 2016; E. Peters, Hibbard, Slovic, & Dieckmann, 2007; Winter & Krämer, 2012). One factor with potential implications for how people understand of scientific information and uncertainty is their view of scientific knowledge and of the scientific process. According to the National Science Board's (NSB) Science & Engineering Indicators, the majority of Americans have some understanding of probability and experimental design but do not know understand what a scientific study is (2018) (Figure 1). The numbers could indicate that the U.S. public has less understanding of the rigor of scientific studies that distinguishes scientific information from other forms of knowledge, which could affect how people perceive the role of uncertainty in the scientific process and research results.

Figure 1:U.S. public understanding of scientific processes, from the General Social Survey (National Science Board, 2018, p. 7.48).

Correct answers to scientific process questions: Selected years, 1999–2016

(Percent)

Question	1999	2001	2004	2006	2008	2010	2012	2014	2016
Understanding of scientific inquiry scale[a]	32	40	39	41	36	42	33	46	43
Components of understanding scientific inquiry scale									
Understanding of probability[b]	64	67	64	69	64	66	65	66	64
Understanding of experiment[c]	34	40	46	42	38	51	34	53	51
Understanding of scientific study[d]	21	26	23	25	23	18	20	26	23

The coding that the NSB applied for defining "understanding of scientific study" is somewhat conservative, and it is important not to take this data on its own as proof of a scientifically ignorant public (see Appendix A for discussion). The U.S. public might have sense of scientific studies that is not captured by the NSB measure but is relevant to how they understand and tolerate uncertainty in scientific information and in the formation of that information. Additionally, knowledge in general, while often significant, rarely plays a large role on its own in shaping individuals' opinions on an issue, in part because of the effects of information presentation (Section II.a.) and individuals' experiences and values (Section II.b.ii).

The NSB indicators could suggest, however, that discussing uncertainty in the context of probability or experimental design could resonate more with public knowledge of the scientific process than would discussing it in the context of hypothesis testing or other parts of the process. Alternatively, describing what makes a study scientific could also make communication of uncertainty – especially uncertainty related to R&R in science – more effective. Research in Section II.b.ii on inducing particular views on the nature of scientific knowledge (epistemic beliefs) to provide important context when communicating uncertainty gives one example of this as a useful approach.

II.b.ii. Value- & belief-based processing – trust and views of science

In addition to ability, when people come across scientific information they process it in ways shaped by values related to the information. Much of this processing is called directional motivated reasoning. As seen with the back-fire effects described in II.a.ii, people are motivated to interpret information in ways biased by their held values in order to avoid value-incongruent information triggering discomfort, or cognitive dissonance, in one's held beliefs (see, for overviews, Festinger, 1957; Kunda, 1990). Trust and epistemic beliefs are two such characteristics that play a significant role in views of scientific uncertainty. Because they are also characteristics for which we have U.S.-representative data, they are the focus of this section.

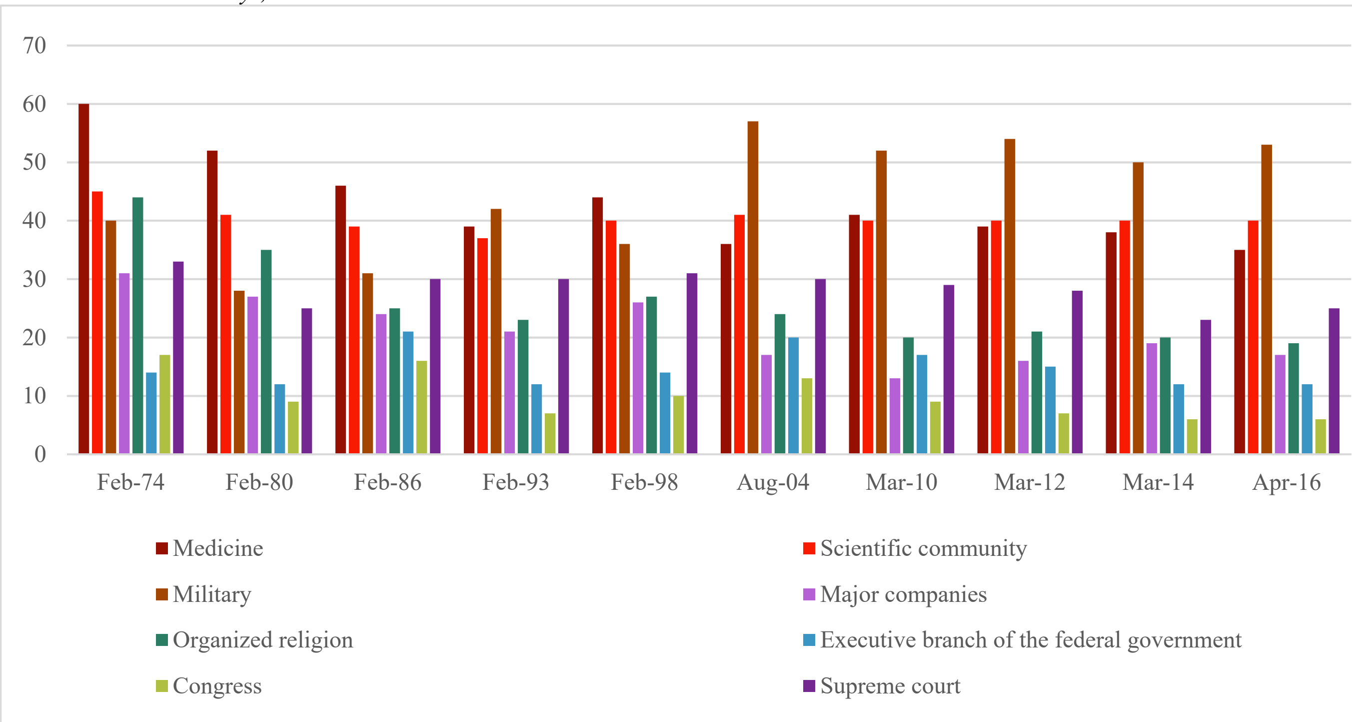
II.b.ii.1. Trust & confidence in scientists

Trust can shape how individuals view information from different sources and the opinions they form about issues related to that information (Freudenberg, 1993; Freudenberg & Pastor, 1992; Kasperson, Golding, & Tuler, 1992; R. G. Peters, Covello, & McCallum, 1997). It plays a key role in how people navigate uncertainty (Engdahl & Lidskog, 2014; Kasperson, 1992), and trust in scientists can affect perceived risk in the face of uncertainty, typically by reducing risk perceptions (Ho, Scheufele, & Corley, 2011; Siegrist, 2000; Siegrist, Connor, &

Keller, 2012; Wachinger, Renn, Begg, & Kuhlicke, 2013). Additionally, levels of trust in scientists relative to trust in other relevant actors – or the "trust gap" between actors – for a given science-related issue can play a significant role in views of the issue (Priest, Bonfadelli, & Rusanen, 2003).

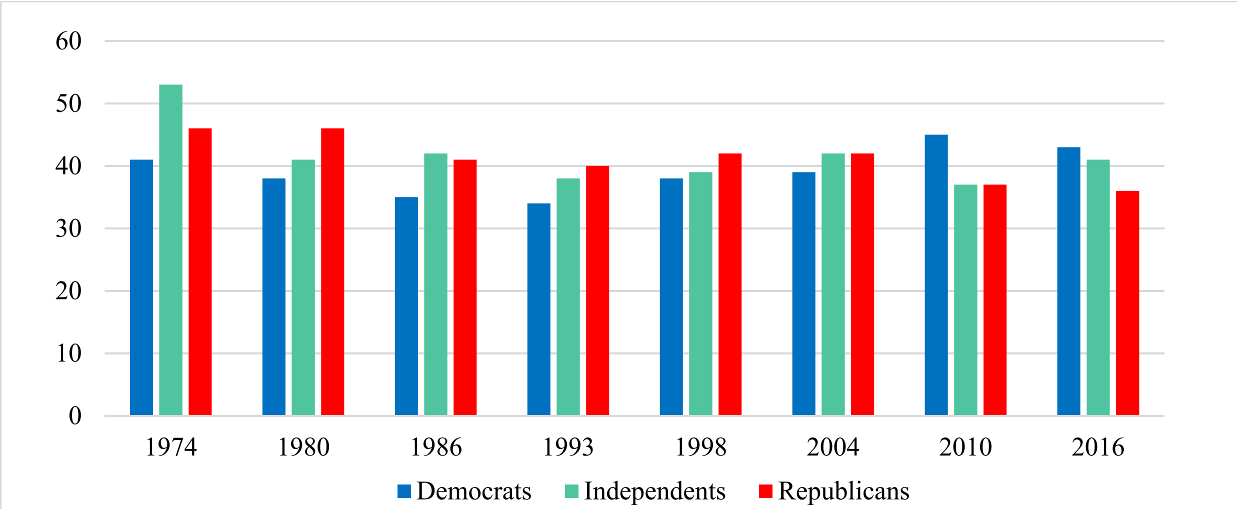
In the U.S, trust in scientists has remained stable over the past few decades, and scientists are one of the most highly trusted groups. Americans who indicate that they have a "great deal of confidence" in the individuals running the scientific community has remained around 40 percent (Figure 2). Compared to all other institutions in the U.S., this level of confidence is especially high – comparable to confidence in the medical community and below only confidence in the military in the past two decades. This confidence has been more stable than has confidence in other institutions, as well. If trust gaps play a role in how people respond to uncertainty in scientific information, then the scientific community ranks ahead of other relevant institutions people look to when forming opinions on issues.

Figure 2: Percent of U.S. adults who indicate that they have "a great deal of confidence" in the leaders of each institution, from the General Social Surveys, 1974-2016.



Trust is also shaped by values that affect information processing, however, such as those captured by political ideology and religious views. Because of these interactions, despite overall high trust levels at the national level, trust within particular groups varies depending on the values individuals hold. For example, those who identify as members of the Republican party today are less confident in the scientific community than are other people (Figure 3). Similar gaps exist between Americans who identify as highly religious and those who do not (those who are not religious indicating greater confidence), Americans who associate with different organized religions, and those who live in urban versus rural areas (those who live in urban areas indicating greater confidence).

Figure 3: Percent of U.S. adults who have "a great deal of confidence" in those who run the scientific community, split by political party identification, from the General Social Survey, 1974-2016.



Part of the reason for these differences could be what type of "science" is most salient in respondents' minds when they answer this question. That Democrats were much less confident in the scientific community from the 1970s-1990s could indicate that "science" for many of those respondents was represented by chemical or war-related industries, or other fields in which the perceived environmental or social impacts do not align with Democratic party values. The change to Republicans being less confident starting in the 2000s could highlight a shift in focus from "science" as industry, for example, to "science" as climate science or connected to environment-focused regulatory policies. The change, at least for the Republican party in recent years, could also reflect that fewer Americans identify as either Democratic or Republican, especially as Republican, and increasingly identify as Independent or unaffiliated, leaving a more ideologically pure, and less trusting, sample in the Republican party. Despite some movement and gaps within groups, however, the U.S. public generally has high confidence in the scientific community.

II.b.ii.2. Epistemic beliefs & views of science

Despite wide availability of data on trust in scientists, there do not appear to be measures capturing general trust in science. Views of the nature of scientific knowledge, however, often called epistemic beliefs, do exist, and research finds that they significantly relate to how people process information on scientific uncertainty. Epistemic beliefs capture whether one sees scientific knowledge as absolute truth, relative, or contingent on context, typically seen as a progression toward increasingly complex epistemic beliefs (Sinatra, Kienhues, & Hofer, 2014). Individuals who hold more complex beliefs are more likely to critically evaluate and perceive uncertainty in scientific information (Feinkohl, Flemming, Cress, & Kimmerle, 2016; Kimmerle et al., 2014; Rabinovich & Morton, 2012). Those individuals are also, however, more likely to view information containing uncertainty as persuasive (Rabinovich & Morton, 2012). Complex beliefs and their effects can be induced prior to communicating uncertainty, as well, by explaining the aims of science and of the scientific process (Rabinovich & Morton, 2012).

As these findings highlight, perceiving uncertainty in scientific results is not necessarily undesirable. It can reflect more accurate views of the strengths and limitations of information. Research on exposure to conflicting information found that this exposure decreased beliefs that it is possible to find one best solution to health issues (Kienhues, Stadtler, & Bromme, 2011), which is likely a more accurate view of the context-dependence of decision-making in health care. Participants did not become “relativized” (seeing scientific knowledge as all relative or opinion-based), however, or helpless and still gained knowledge about health and medical information despite the exposure to conflict (Kienhues et al., 2011). Additionally, communicating uncertainty in news stories about a particular science topic does not appear to change beliefs about the nature of science in general (A. Retzbach & Maier, 2015). These findings suggest that people can have a higher tolerance for scientific uncertainty than communicators might expect and that uncertainty in a particular story will not necessarily bleed into views of science overall. As the findings on hedges increasing credibility indicate as well, people even appear to expect a level of uncertainty in scientific information. This is counter to beliefs research finds many scientists hold of the public as having a primarily risk-focused view of science (Braun, Starkbaum, & Dabrock, 2015) and not being able to understand or "correctly" handle scientific information (Besley & Nisbet, 2011; Davies, 2008; Ecklund, James, & Lincoln, 2012), and that providing the public with information on uncertainty creates distrust, panic, and confusion (Frewer et al., 2003).

Related to public tolerance for uncertainty are the findings that interest in science and positive attitudes toward science can also increase perceptions of scientific uncertainty (Kohl et al., 2016; J. Retzbach, Otto, & Maier, 2016) and, vice versa: exposure to scientific uncertainty can sometimes increase interest in a particular science issue (A. Retzbach & Maier, 2015). These relationships between uncertainty in science and interest in science illustrate how perceiving uncertainty does not mean being "anti-science." As the above-mentioned studies indicate, often the opposite is true – perhaps because those with the greatest familiarity with science are more likely to hold more complicated epistemic beliefs, rather than viewing scientific information as absolute or all relative.

II.c. *Recommendations for communicating uncertainty related to reproducibility & replicability*

Based on the literature review above, several considerations can aid communication of issues of R&R in science and of uncertainty related to R&R.

1. Uncertainty is necessary to communicate to accurately provide scientific information.

2. **Communicating uncertainty through hedges appears to be expected by the public and can increase perceived credibility of that information.**

3. **Conflict between researchers in stories can unnecessarily increase perceptions of uncertainty, but communicators can accurately describe existing disagreements by explaining sources of uncertainty and disagreement and the steps researchers take or are taking to address them.**

   Describing the sources of uncertainty and conflict, and steps taken to address it, can also avoid negative frames around an issue, which can then decrease perceptions of uncertainty and sometimes increase proactive responses to an issue. When negative frames do exist, people appear to prefer additional and precise information, even when it is contradictory, so explaining sources of uncertainty and conflict can also add precision that helps provide people with the information they seek.

   <u>*In the modern media system*</u>: Including why and how disagreement exists and how researchers are addressing within stories it is especially important because the media environment can increase exposure to conflicting information, as described in Section II.a.ii. Addressing common sources of disagreement within one story, then, can provide context for people when they encounter additional, potentially conflicting, information.

4. **If misperceptions of the levels, sources, and implications of uncertainty do arise, corrections are most effective when they coherently "fill the gap" in the story that the misinformation originally filled and explain why the misinformation arose in a way that focuses on the misinformation itself (rather than actors who spread it) and that aligns or does not clash with beliefs or worldviews of those more likely to hold the misperception.**

   <u>*Within the modern media system:*</u> Although spread of information through traditional and online sources is difficult to predict or control, online and social media in particular offer outlets for effective corrections of misinformation, through tweets from expert sources and links to related stories.

5. **Effective communication of uncertainty related to R&R should explain the role of R&R in scientific research, why R&R sometimes fails for certain studies, and what researchers will do and are doing to improve levels of R&R.**

As mentioned in the section on individual characteristics, epistemic beliefs affect how people interpret and respond to information on scientific uncertainty, and these beliefs can also be induced by explaining characteristics of scientific research and how those characteristics relate to producing reliable and valid knowledge. Additionally, as much of the public does not appear to have clear or easily retrievable understanding of what makes studies scientific (section II.b.i., Figure 2) and R&R is not particular salient to the greater public (Part 2 of this study), describing the role of R&R can provide context that helps people sort subsequent information, explains potential sources of and solutions to disagreement, and increases tolerance for uncertainty in scientific information.

III. Part 2: Media Reporting of Reproducibility & Replication in Science

Moving from individuals' perceptions to media coverage, coverage of science shapes what uncertainty information people have access to and the presentation of that information, as Part 1, Section II.a.ii described. The following section describes coverage within the past decade on R&R of scientific results on Twitter, YouTube, Google search results, and news articles.

Little coverage exists, and a few key R&R studies drive news coverage and Twitter discourse, particularly studies focused on the fields of psychology or cancer and biomedical research. Background discussion on R&R as necessary features of science or as parts of specific studies, not explicitly focused on a crisis, remains more constant in news and Twitter coverage as the coverage on an R&R crisis comes and goes. Top sources on YouTube and Google Search are academic and science-focused sources. This, combined with the overall relatively low levels of coverage in news outlets and on Twitter, suggests that R&R as features of science or as indicative of crisis in scientific fields are not especially salient in the greater U.S. public. This section discusses the results and implications of media coverage of R&R.

III.a. *Online & print news coverage from 2008-2018*

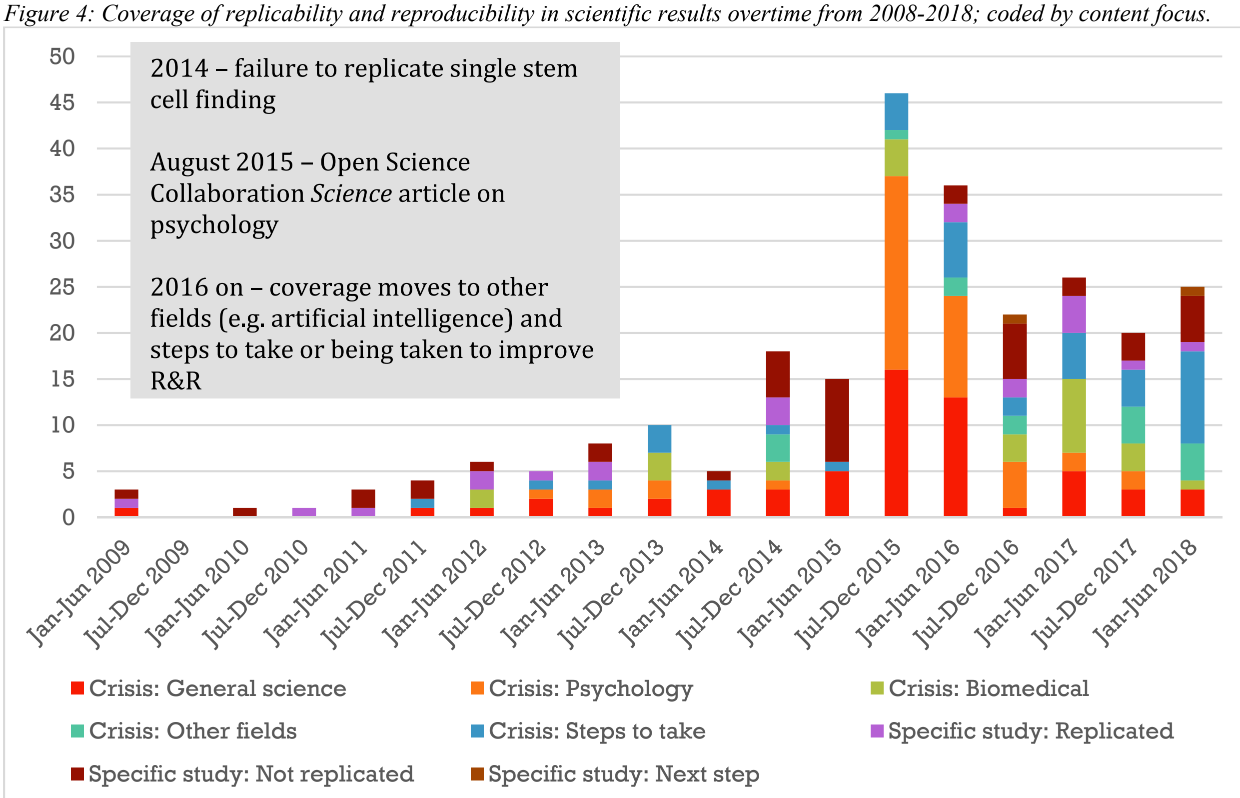
News coverage on R&R in print and online news outlets over the past decade is low but has increased over the past four years and remained at a higher base level following peaks in coverage triggered by key R&R studies focused on particular studies or scientific fields (Figure 4). A search of news headlines focused on R&R in science or in scientific results combined with a search of entire newspaper, blog, online-only, and magazine stories[2] in the database NexisUni – a database of articles from approximately 11,000 outlets – from June 1, 2008 to June 1, 2018 captured 254 unique, on-topic articles. Coverage focused on either: 1) the R&R crisis in general or in a particular field, or 2) a particular study (not explicitly situated in the greater context of the R&R crisis) that was or was not replicated/reproduced or that needed additional research to be replicated/reproduced (Figure 4). Articles often interchangeably used the terms reproducibility and replicability.

Coverage was low (0-10 articles per year) from 2008 to 2013. Starting in 2013, coverage of R&R as part of a crisis in science increased (articles coded with *Crisis* in Figure 4). Coverage peaked at 46 articles in August 2015, following Open Science Collaboration's article in *Science* reporting that 36 percent of 100 studies in psychology research were reproduced (Open Science

[2] Search string: [*headline*]*((finding* OR result* OR study OR studies) AND (replicab* OR replicat* OR reproduc*) AND NOT (soccer OR football OR ranking* OR game OR win OR club OR quarter OR reproductive OR reproduction OR "self-replicat*" OR "replicate itself" OR "replicate themselves" OR "virus* reproduce*" OR "virus* can reproduce" OR "virus* can replicate" OR "virus* replicate*"))*

Collaboration, 2015). An earlier uptick in coverage in August 2014 emerged from articles on researchers' inability to replicate a finding in stem cell research and the original author eventually pulling their study (see Cyranoski, 2015 for an overview) (coded as *Specific study: Not replicated*). Important to note is that coverage focused on a specific study not being replicated includes stories on researchers failing to replicate the retracted article that falsely linked autism to vaccinations and stories such as the stem cell research mentioned above.

Figure 4: Coverage of replicability and reproducibility in scientific results overtime from 2008-2018; coded by content focus.



Coverage on R&R as indicative of a crisis decreased in the past two years (2016 to spring 2018) but remains higher than it was before the release of the Open Science Collaboration article (2015). Content continues to focus on psychology (*Crisis: Psychology*) but has moved to R&R issues in other fields as well, such as cancer research or genomics (*Crisis: Biomedical*) and, most recently, artificial intelligence (coding within *Crisis: Other fields*, which includes articles on health, economics, education, advertising, and legal research). A growing portion of crisis-related content now focuses on what steps the scientific community should or is taking to increase likelihood of replicating or reproducing results (*Crisis: Steps to take*).

III.b. *Google Search results for reproducibility/replicability (crisis)*

In addition to the news content described above, Google Search results from searching the terms "Reproducibility," "Replicability," and "Reproducibility [Replicability] Crisis" provide insight into what types of information users are most likely to see if trying to learn more about R&R in science. This analysis includes results from Google Search during May 2018 from only the first page, as most Americans rely on Google for accessing information online (Purcell et al., 2012) and most searchers do not go past the first page of results (Chitika Insights, 2013). This data on its own provides a small snapshot that can supplement the other, more exhaustive descriptions of news, YouTube, and Twitter content. To avoid previous search history biasing the results, the searches were conducting after clearing the browser history and using Google Chrome's incognito mode.

The four searches yielded 40 unique sources, 15 of which focused on defining R&R either in general or as part of scientific methods (Table 1). Of the remaining 25 sources, academic journals (10 articles) and other types of academic or science-focused sources dominate the sources, including university-affiliated webpages (three links), the American Psychological Association (one link), and science news outlets such as *Nature News & Comment*, *Science Magazine*, and *NOVA* (10 links). News outlets not exclusively focused on science issues, such as *Slate* and *The Atlantic*, are four of the links. Seven results focused on psychology and three focused on other scientific topics (two on biomedical research and one on artificial intelligence).

Most of the results state that scientists are discussing R&R, pose a question ("Why should scientific results be reproducible?" from *NOVA*), or state that claims of a crisis are either overblown or indicative of advancing science ("No Evidence for a Replicability Crisis in Psychological Science," posted on a website hosted by the Psychology Department at Harvard, and "Failure Is Moving Science Forward" from the blog *FiveThirtyEight*). *The Atlantic* has the most negative tone: "Psychology's Replication Crisis Can't Be Washed Away."

Table 1: Google Search first page results, May 2018, by source type and content (categories not exclusive).

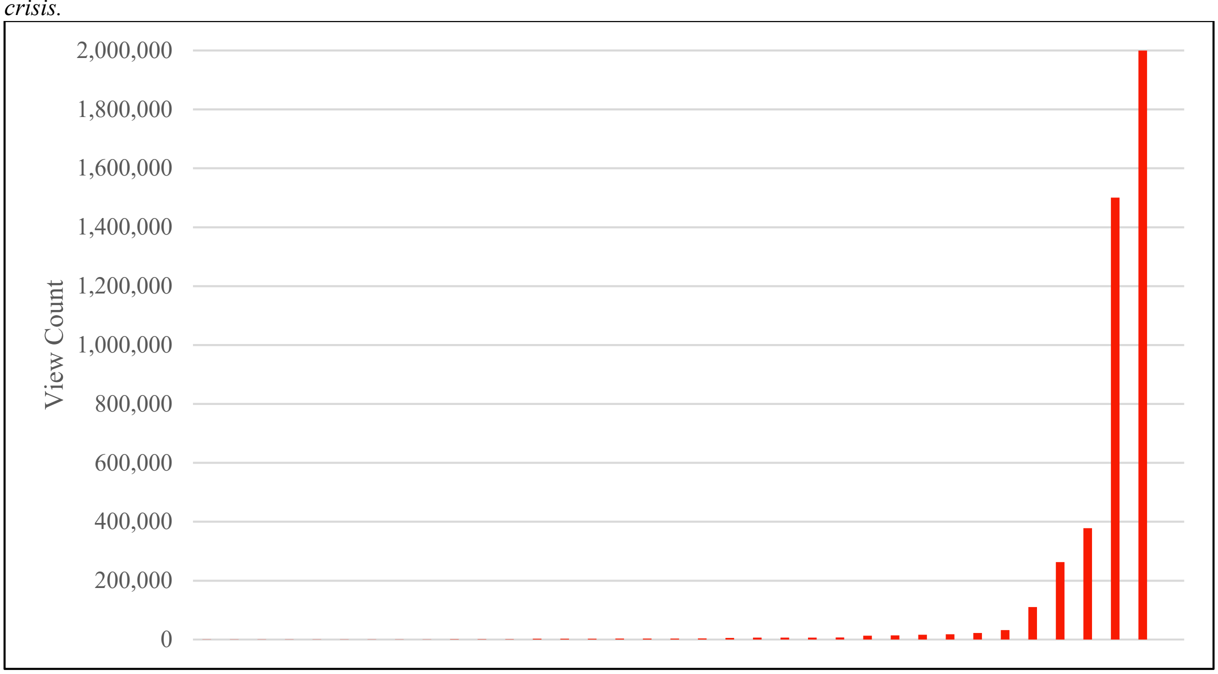
Search Term	***Reproducibility***	***Reproducibility Crisis***	***Replicability***	***Replicability Crisis***	*Total (# unique)*
Total first page results	**10**	**12**	**10**	**10**	**42** ***(40)***
Definition	**5**	**2**	**8**	**1**	**16** ***(15)***
Academic Journal	**3**	**3**	**1**	**3**	**10** ***(9)***
Science/education-focused news outlets	**4**	**6**	**1**	**0**	**11**
General news outlet	**0**	**2**	**0**	**2**	**4**
University-hosted page	**1**	**0**	**1**	**1**	**3**
Psychology-focused	**0**	**0**	**2**	**5**	**7**
Other science-field focused	**0**	**2** - biomedicine **1 –** AI	**0**	**0**	**3**
Science-in-general focused	**7**	**8**	**1**	**4**	**20** ***(19)***

III.c. *YouTube videos on reproducibility and replicability*

In addition to Google Search, most Americans regularly get online science information from science videos (Funk, Gottfried, & Mitchell, 2017), of which YouTube is one of the top resources. To understand what types of content people are likely to encounter on YouTube when seeking information on R&R, this overview describes the top ten videos by relevance (what YouTube's algorithm decides is relevant to the search terms) and by view count using the same search terms and methods described in the Google Search analysis (Section III.b). Searches using more general terms (e.g. "science wrong") generated primarily off-topic videos and therefore are not part of this description.

Similar to the Google Search results, most results are from academic sources – typically conference presentations – or from top science-focused publishers on YouTube (such as *Veritasium* and *SciShow*). The four searches together produced 35 unique videos (excluding 6 off-topic videos). As Figure 6 illustrates, view counts follow a power curve, which is typical of attention numbers across online sites (Hindman, 2009). View count ranges from 32 to 12,000,000 (a *Last Week Tonight* segment by John Oliver, not included on Figure 6).

Figure 5:View count for the top videos on YouTube focused on reproducibility, replicability, and reproducibility/replicability crisis.



For brevity, the five videos with the most views provide some context into the content and reach of R&R-focused videos YouTube users would be more likely to see, and these top five are the only ones with greater than 100,000 views. As seen in Table 2, they primarily are from science-focused channels, except for the John Oliver *Last Week Tonight* segment. That video is the 21st most popular on the *Last Week Tonight* YouTube channel. Its subhead describes it as "John Oliver discusses how and why media so often report untrue or information as science" (Last Week Tonight, 2018), so the frame appears to be more on media reporting of science rather than R&R in science or science in crisis.

Figure 6:Top five videos by view count on reproducibility, replicability, and/or reproducibility/replicability crisis in science.

Video Title	Author	Views	Age
Scientific Studies: Last Week Tonight with John Oliver (HBO)	LastWeekTonight	12,000,000	1 year
Why an Entire Field of Psychology Is in Trouble	SciShow	2,000,000	2 years
Is Most Published Research Wrong?	Veritasium	1,500,000	1 year
Is there a reproducibility crisis in science? - Matt Anticole	TED-Ed	263,000	1 year
Reproducibility Issues in Life Science Research Documentary: Antibody Validation Challenges	Biocompare	110,000	9 months

The other four videos come from either science- and education-focused channels (*SciShow*, *Veritasium*, and *TED-Ed*) or from Biocompare – a company focused on products for researchers in the life sciences (Biocompare), which made a documentary on reproducibility in life sciences research. *SciShow* and *Veritasium* are in the top-five most popular science-focused YouTube channels, and although their videos on reproducibility have more than a million views, they are low in popularity compared to many of the channels' other videos (see Appendix B for description of the results compared to other science content on these channels). This suggests that the topic is not especially popular, even on science-focused channels.

III.d. *Discourse on Twitter from 2008-2018*

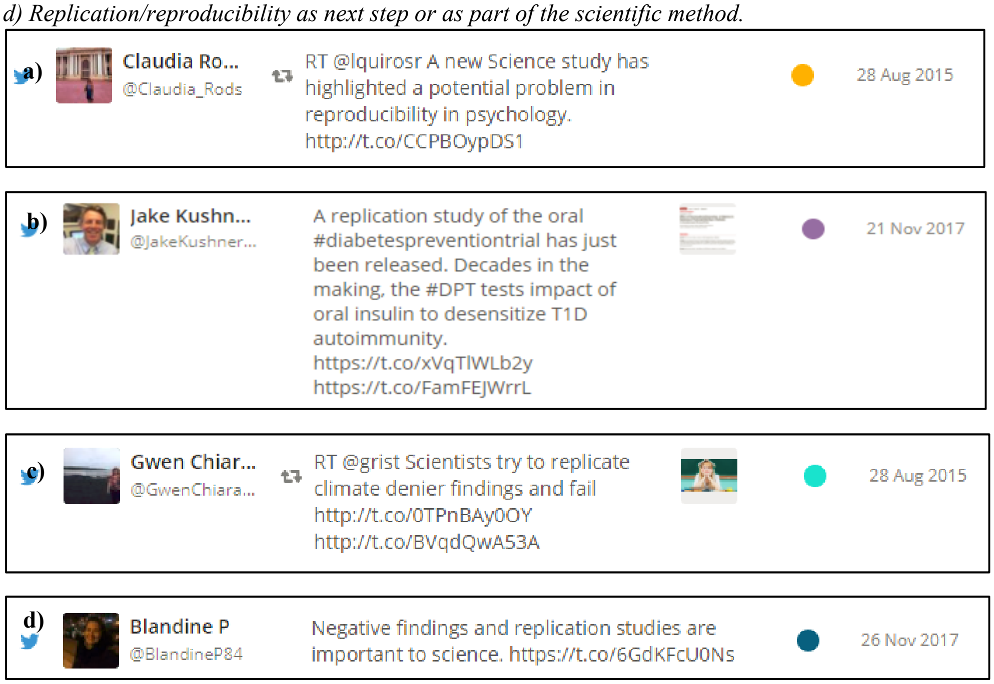
Finally, Twitter discourse can offer a sense of a broader conversation on R&R in science. The same search terms and timeframe described for the news article search (Section III.a) was used to collect all Twitter posts (tweets) on R&R in scientific research. This analysis used *Crimson Hexagon Forsight* software, a program that combines human- and computer-coding to categorize a large sample of tweets (Hopkins & King, 2010), although comparable analysis could be conducting using open-access programs such as R. Human coders categorized tweets as on- or off-topic (319,516 total tweets captured, 193,471 on-topic (61%)). They then sorted a sample of 100 on-topic tweets according to the coding listed below. The *Forsight* algorithm then applied that coding to the body of tweets. Inter-coder reliability between the two human coders was 84 percent (Krippendorff's alpha, for a more conservative measure of reliability, was 0.71).

Twitter discourse falls into three types of discussions:

1) Tweets focused on an R&R crisis, or R&R as a problem in science or in particular science field (labeled: *Replication/reproducibility as problem*). These tweets focus on R&R failures across larger bodies of scientific work, connected individual R&R studies to broader R&R problems in science, or cited steps researchers can or are taking to understand why R&R failures occur and how to remedy them (see Figure 8a for example tweet).
2) Discourse focused on an individual study either replicating/reproducing or failing to replicate/reproduce another study, without a mention of R&R as key parts of science or an R&R crisis in science. This group is separated into two subcategories: a) a study replicated another study (labeled: *Study replicated/reproduced*) (Figure 8b), or b) a study failed to replicate another study (labeled: *Study not replicated/reproduced*) (Figure 8c).
3) Tweets focus on *replication/reproducibility as next step or as part of the scientific method* (Figure 8d), which refers to R&R as parts of the scientific process in general or highlights that an initial finding should be replicated as a next step in the scientific process. It does not focus on lack of R&R as indicative of a crisis in science or in particular scientific fields. The distinction between tweets focused R&R as a crisis and tweets focused on R&R as part of the

scientific method, however, was not always as clear as the distinctions between the other categories.

Figure 7: Examples of tweets from each coding category: a) "Replication/reproducibility as problem"; b) "Study replicated/reproduced"; c) "Study not replicated/reproduced"; d) Replication/reproducibility as next step or as part of the scientific method.



Of on-topic discourse, 47 percent focused on R&R as a problem in science or in particular scientific fields (Figure 9). Mirroring the news coverage, tweets peaked in 2015 (Figure 10), driven by discourse on the Open Science Collaboration article in *Science* article on failing to reproduce most findings across 100 studies in psychology. Tweet volume, especially about an R&R crisis, dropped steeply after 2015 but generally remains higher than pre-peak levels. Many tweets on an R&R crisis simply retweet study findings free of additional commentary. Retweets of the Open Science Collaboration article or of news organizations' tweets about that article's findings are a large driver of the summer 2015 peak. Discourse in remaining categories remains at relatively constant and low background levels, especially discourse on replication/reproduction as a feature of science more generally.

Figure 8: Percent of on-topic tweets concerning reproducibility and replicability in science, by category, June 2008-May 2018.

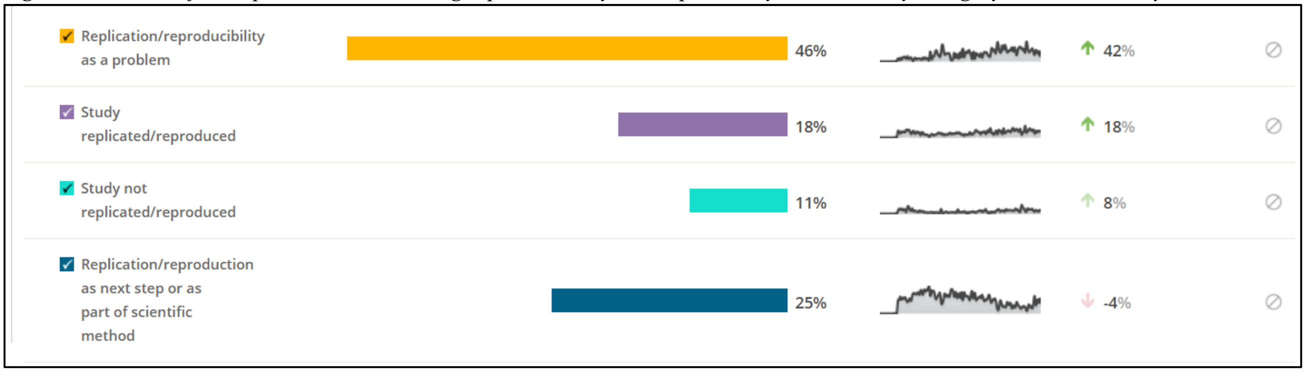
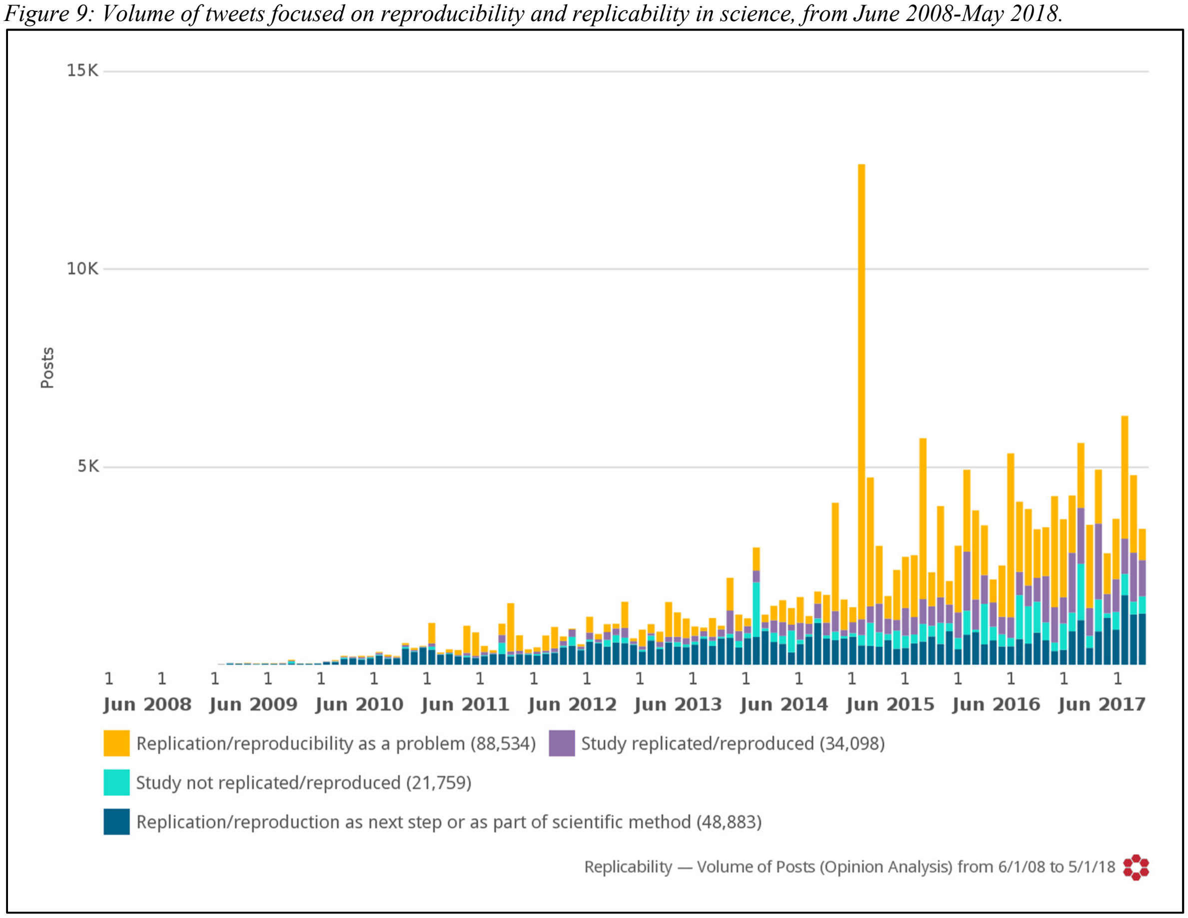
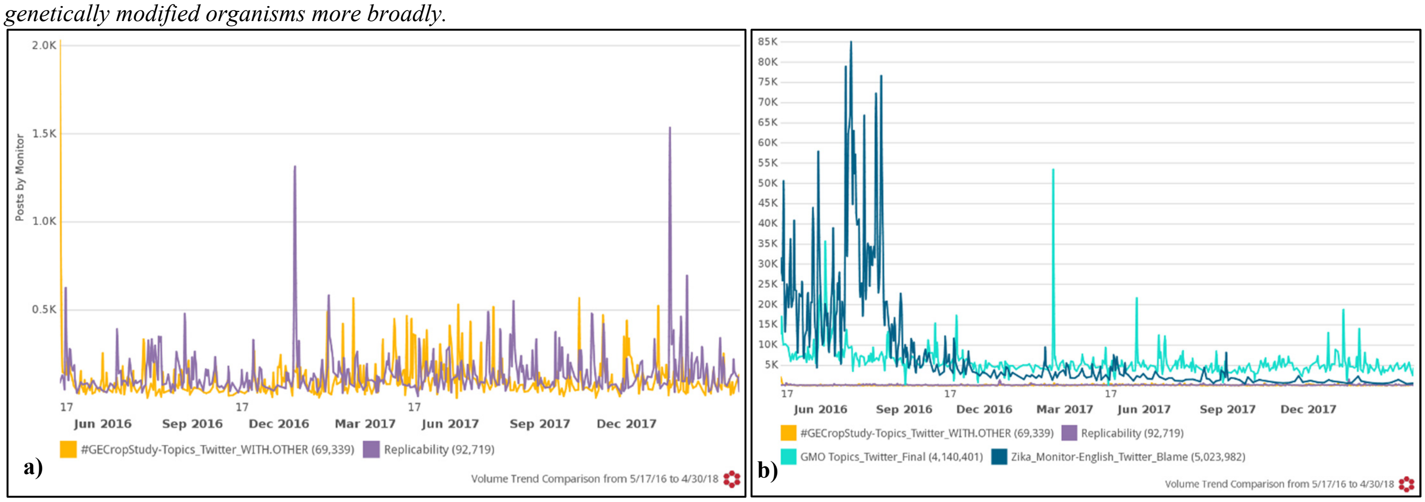


Figure 9: Volume of tweets focused on reproducibility and replicability in science, from June 2008-May 2018.



To get a sense of the size of the conversation, Figures 11a & 11b position the volume of tweets on R&R next to volume of tweets on other science-related topics available from previous research using *Crimson Hexagon*. These topics range from more popular science-related discourse (tweets about GMOs and tweets that blame different actors for the Zika crisis) to more obscure (tweets on the release of the NASEM report on “Genetically-Engineered Crops: Experiences and Prospects). As seen in Figures 11a-b, tweets on R&R (labeled *Replicability* in Figure 11) are comparable in volume to those specifically focused on the NASEM report on genetically-engineered crops in the year-and-a-half following the NASEM report’s release in spring 2016 (labeled *#GECropStudy. . .*; Figure 11a) (Howell et al., forthcoming). Both topics are dwarfed by the conversations on GMOs (labeled *GMO_Topics. . .*; Figure 11b) (Howell et al., forthcoming) and tweets specifically blaming a corporate, government, or other actor for the Zika outbreak (*Zika-Monitor. . .*) (Wirz et al., forthcoming). Together with the fact that 58 million Americans use Twitter (Shearer & Gottfried, 2017) these results suggest that the conversation around R&R in science is a small although somewhat constant part of Twitter discussion in recent years.

Figure 10: Comparison of volume of tweets focused on a) the release of the NASEM report on genetically-engineered crops and reproducibility & replicability in science and b) both topics in contrast to discourse blaming institutional actors for the Zika virus outbreak and discourse focused on genetically modified organisms more broadly.



IV. Discussion

IV.a. Media coverage of reproducibility & replicability

As seen in the media coverage in news outlets and on Twitter, as well as in the most popular relevant content on Google Search and YouTube, media discourse concerning R&R in science is a relatively small conversation compared to other science topics and is largely dominated by academic sources and science-focused outlets. Discourse on Twitter and online and print media coverage have increased in recent years, both peaking with the Open Science Collaboration article in 2015 on reproducibility in psychology (Open Science Collaboration, 2015). Coverage has dropped since then but remains higher than it was pre-2015. On Twitter, much of the background conversation is focused not on R&R as indicative of a crisis in science but on R&R as features of the scientific process and on particular studies that either replicate/reproduce or fail to replicate/reproduce previous studies, separate from conversations that place such studies in the context of a problem in science. Much of the discourse and coverage across platforms is field-specific, rather than focused on "science" in general. It also increasingly focuses on steps to take or that are being taken within the scientific community to improve R&R.

Overall, the results indicate that R&R in science are likely not especially salient among the broader U.S. public, however, the size and focus of coverage described here cannot give complete insight into the impact of coverage. Impact depends on who the information reaches and how it interacts with their held beliefs and goals (as described in Section II) as well as the influence of the people the information reaches. There is the potential for certain publics (often called "issue publics") that pay more attention to an issue to have a larger influence on discourse and decision-making around that issue (Converse, 1964; Li et al., 2016; Price, David, Goldthorpe, Roth, & Cappella, 2006). Based on the heavily academic- and science-based sources of R&R-focused content on the mediums outlined here, it appears that researchers themselves are playing the role of issue public in the current discourse and decisions concerning R&R. As uncertainty and perceptions of uncertainty can also be a political tool, however, interested groups could use discourse on R&R as a way to argue for particular action or inaction. As coverage increasingly focuses on steps researchers and academic journals should take or are taking to improve R&R, it appears that actors currently shaping the discourse are addressing the uncertainty by trying to understand and improve issues in R&R.

IV.b. Public views of scientific uncertainty

That media often focuses on specific fields mirrors findings on public perceptions of uncertainty that indicate that how people view uncertainty in science depends on the particular study or scientific issue of focus. Several factors suggest that views of uncertainty in a particular field are unlikely to fully bleed over into science-related views in general for most of the public. The main indication of this is the highly context-dependent nature of perceptions of uncertainty, as described throughout Part 1. Additionally, as people often hold different views of the rigidity of different fields (e.g. mathematics is seen as most structured and social fields as less structured (Buehl & Alexander, 2001)) and have varying levels of trust for different scientific actors depending on the issue, views of "science" are likely better understood as views of multiple types of scientific issues, fields, and actors, which vary in saliency across different populations over time and depending on context.

Despite those variances, communicating uncertainty appears to be most accurate and effective when it includes caveats from scientists involved in the research and avoids conflict between scientists, such as scientists contradicting each other or attacking each other's work without providing caveats for their own perspectives or for the sources of disagreement. Conflict between researchers' interpretations can be accurate portrayals at times but can also be counterproductive to addressing uncertainty if communication does not include the reasoning behind disagreements. In the case of communicating disagreements around R&R, combining discussion of any sources of uncertainty and conflict will be more effective if it gives context for the uncertainty both as it relates to the particular study or field of focus as well as how R&R and uncertainty relate to scientific research and processes in general (if the goal is toward addressing R&R issues and concerns). For the particular study and field, this could be done by not only explicitly acknowledging uncertainty, its sources, and its potential implications, but by also including the steps researchers can and are taking to address it and how R&R fits in that process.

IV.c. Conclusion

Because of its context-dependence, uncertainty appears to rarely be the sole or determining factor in views concerning a particular science-related issue. As researchers focused on science in policy arenas have highlighted, uncertainty instead can often create space for other values, considerations, and goals to come into play as stakeholders debate how to act on information (Campbell, 1985; Post & Maier, 2016; Renn, 1992). That space for discussion and interpretation created by uncertainty is part of why it is necessary to communicate scientific uncertainty well so that actors can make well-informed decisions. It is also why, however, it is important to understand how perceptions of uncertainty will be shaped by the interactions between information presentation (both within and across stories and mediums) and individual values, goals, and beliefs concerning scientific information and issues. With these variations in mind, clear from the literature is that uncertainty in scientific information does not inherently translate to lack of credibility. For many members of the public, uncertainty in science is expected and scientific information on uncertainty an indicator of the credibility of the messenger of that information and of the information itself.

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Appendix A. *Descriptives of U.S. public's understanding of scientific studies*

To qualify as understanding scientific studies, respondents had to indicate that they had a clear understanding or general sense of what the term "scientific study" means and then give an open-ended response stating that studying something scientifically involves formulating theories, testing hypotheses, running experiments with control groups, or making rigorous or systematic comparisons (National Science Board, 2018, p. 7.48). The GSS data indicate that 80 percent of respondents believe they have a clear understanding or general sense of what a scientific study is, but only 28 percent of those individuals gave sufficient answers in the open-ended portions (NORC, 2017, pp. 1778-1779). This suggests a disconnect between perceived and measured understanding that could indicate that individuals are overconfidence in their own knowledge or could indicate that the researchers applied a strict definition of "understanding" when coding the open-ended item.

The steep discrepancy in answers holds across populations with high levels of education in general and in math and science fields in particular, which could further suggest that the measure of understanding scientific studies is a rather strict one. Eighty percent of individuals with a graduate or professional degree understand probability and experiment design, but only 42 percent qualify as understanding a scientific study – a surprisingly large disconnect between related types of understanding among a highly educated population (National Science Board, 2018, appendix table 7-11). Similarly, looking at individuals with a high level of science and mathematics education (having taken eight or more high school and college level courses), 84 percent understand probability, 77 percent understand experimental design, but only 50 percent qualify as understanding a scientific study (National Science Board, 2018, appendix table 7-11).

Appendix B. *Comparison of top YouTube videos of R&R to other top science videos*

For *SciShow*, its top ten videos have between 4.4 and 8.2 million views and new videos consistently receive more than 100,000 views in a few days. "Why an Entire Field of Psychology Is in Trouble" is 35th in popularity, behind videos on "The Deepest Hole in the World" (number one in popularity with 8.2 million views in four years), "The Terrifying Truth About Bananas" (6.1 million in four years), and "Why Avocados Shouldn't Exist" (4.1 million in the same time span as the video on replicability in psychology) (SciShow, 2018).

The video through *Veritasium* ("Is Most Published Research Wrong?") has 1.5 million views in a year, but the channel's top ten videos range from 36 million views ("Surprising Applications of the Magus Effect," 2-years-old) to 5 million ("Stringless Yo-Yo!" 1-year-old). "Is Most Published Research Wrong?" comes in at 70th and outlines what reproducibility and replicability are (Veritasium, 2018). It concludes that even if particular studies at any given time are not reproduced or replicated, the process is what distinguishes scientific information as more rigorous than other information.

The *TedEd* video "Is there a reproducibility crisis in science?" has 264,000 views and does not appear on the video upload page when sorted by most popular videos, meaning it is below the top 200 of the channel's videos (TED-Ed, 2018).