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Abstract

Uncertainty is inherent to science and science communication. However, the evidence appears mixed regarding whether portraying uncertainty in science communication has positive or negative effects. We review a diverse range of experimental literature (*k* = 48; from 40 searches and 8000 retrievals), summarize the extant findings, and observe how the effects vary across four different types of communicated uncertainty (*deficient, technical, scientific,* and *consensus uncertainty*). The results indicate that most findings of negative effects (such as reduced credibility and beliefs) are from experiments that operationalized uncertainty as disagreement or conflict in science (*consensus uncertainty*). In this review, consensus uncertainty was never found to have positive effects. In contrast, uncertainty in the form of quantified error ranges and probabilities (*technical uncertainty*) in these studies has had only positive or null effects, not negative effects. We also highlight frequent moderators of the effects of uncertainty, such as prior beliefs and worldviews.

Keywords: literature review; uncertainty; science communication; experiments; framing

A Review of the Effects of Uncertainty in Public Science Communication

A Systematic Review

Uncertainty is inherent to the nature of science and scientific knowledge. Indeed, two familiar epistemological conceptualizations are that science can disprove hypotheses but can only provisionally support hypotheses (Popper, 1959), and that science moves in paradigmatic cycles in which discoveries can spark a rejection of longstanding assumptions while also introducing new uncertainties (Kuhn, 1970).

Further, the competitive, iterative, and unending nature of scientific progress necessarily and usefully breeds conflicting theories and competing hypotheses (Shanteau, 2000). Even when reporting findings on which there is relative agreement, scientists often describe a degree of uncertainty surrounding a parameter. Statistical science itself is an exercise in specifying uncertainty with precision by making estimations of variation and error. Consequently, responsible science communication involves describing the current state of uncertainty in deliberate terms (Carpenter, 1995).

Scholars argue it is important to convey the uncertainties of science in public-facing science communication (e.g., journalism, media, public campaigns) so that the public is not misled and can make informed decisions (Campbell, 2011; Stocking, 2010). Scientific press releases often include caveats, and these lead to more caveats in the subsequent journalism coverage (Sumner et al., 2016), varying in quality and accuracy relative to the type, source, and subject of uncertainty (Rice, Gustafson, and Hoffman, 2018). However, journalists sometimes do misrepresent the uncertainties of science, for example, by presenting complex or preliminary information as being more certain than it truly is (Brechman, Lee, and Cappella, 2009; Jensen, 2008; Lai, Lane, and Ruttenberg, 2009; Retzbach and Maier, 2015). This is sometimes done to increase clarity and simplicity for uninitiated lay audiences (Ebeling, 2008), and sometimes out of fear of inviting adverse effects such as increased motivated skepticism and reduced credibility perceptions (Stocking, 1999).

Given the varying extent and accuracy of portrayals of uncertainty in science communication, it is imperative to develop an understanding of whether, when, how, and why communicating uncertainty influences the perceptual, attitudinal, and behavioral responses of audiences. Even finding that uncertainty has no significant effects would be of great importance, because it might enable science communicators to more freely discuss the inevitable uncertainties of science. However, the extant experiments testing the effects of uncertainty vary widely in design, research fields, and results, resulting in considerable inconsistency.

Here, we first explicate the fundamental concept of uncertainty, the inconsistency in its effects, the use of uncertainty as a common frame in science communication, and a typology of uncertainty portrayals. Then we present a systematic review of the experimental literature that has tested the effects of uncertainty portrayals in public science communication. We apply the uncertainty typology to observe whether such distinctions can reduce some of the apparent inconsistencies in the results. Organizing the otherwise inconsistent research this way reveals three patterns: one particular type of uncertainty has shown consistent negative effects, another type of uncertainty has shown almost exclusively positive and null effects, and the individuals' prior beliefs and attitudes frequently moderate the effects of uncertainty. These observations reinforce the value of distinguishing different types of uncertainty portrayals, and provide a better understanding of the effects of uncertainty frames in science communication.

Uncertainty in Science Communication

The Nature of Uncertainty

Uncertainty permeates our perceptions, experiences, and understandings of the world. It is "any deviation from the unachievable ideal of completely deterministic knowledge of a relevant system" (Walker et al., 2003: 8). Uncertainty also exists as an individual's belief, perception, or feeling such as "when details of situations are ambiguous, complex, unpredictable, or probabilistic; when information is unavailable or inconsistent; and when people feel insecure in their own state of knowledge or the state of knowledge in general" (Brashers, 2001: 478). In addition, uncertainty is often communicated in a message via descriptive, qualifying content that references relevant ambiguities, imprecisions, hedges, doubts, and possible alternatives. van der Bles and colleagues (2019) describe the characteristics of communicated uncertainty as being *who* communicates it, *what* uncertainty is communicated, using which *form*, to *whom* is it communicated, and with what *effect*.

A particular portrayal of uncertainty is shaped in large part by the portrayed *causes* of the uncertainty, such as measurement error, random variation, unobservable projections or models, out-of-sample generalizations, disagreement among experts, conflicting evidence, a deficit of extant data, an expanding problem space, an alternative set of underlying models and assumptions, or fundamental unfalsifiability (Broomell and Kane, 2017; Pidgeon and Beattie, 1997; Rice et al., 2018; Zehr, 2000). To accurately communicate the limits of knowledge and the presence of uncertainty, scientists often report "findings" or "conclusions" of scientific research as being bounded, qualified, or otherwise limited by one or more of these types of uncertainty.

Uncertainty about the Effects of Uncertainty

Given the importance of science communication in society (Jamieson, Kahan, and Scheufele, 2017), it is crucial to determine the effects of portraying uncertainty about science. However, while many scholars have investigated this question, the extant evidence appears inconsistent as to whether it has *positive* or *negative* effects. Throughout this review, we use "negative effects" as those that indicate a significant decrease in belief in, perceived credibility of, or intentions to follow the recommendations of the message. Conversely, we refer to "positive effects" as a general label for effects that indicate a significant increase in belief in, perceived credibility of, or intentions to follow the recommendations of the message. Naturally, increased risk perceptions or behavioral intentions could be a negative or positive effect, depending on the position advocated by the message.

Some research suggests that communicating uncertainty about science will instigate, perpetuate, or exacerbate more *negative* attitudes toward scientists and their claims. Scholars explain this effect by arguing that humans tend to be ambiguity-averse (Camerer and Weber, 1992; Keren and Gerritsen, 1999) because uncertainty is often difficult to understand and ambiguity can cause confusion or other negative reactions (Han, Moser, and Klein, 2007; Tversky and Shafir, 1992). Uncertainty can also cause people to justify continuing in their current state rather than responding to information with adaptive action (Budescu, Rapoport, and Suleiman, 1990). Specific to science communication, people often expect experts to be precise and confident (Shanteau, 1987), partly because many people do not understand the role of uncertainty in science (Roth et al., 1990). Accordingly, some surveys indicate that perceived uncertainty among scientists is negatively related to supportive attitudes (e.g., Ding et al., 2011), and some experiments show negative effects of portraying uncertainty on beliefs, attitudes, and behaviors in the context of science communication (see Results).

However, there is also reason to expect that uncertainty can have *positive* effects on attitudes and behaviors, furthering the goals of the message. Evidence from the risk communication literature indicates that portrayals of uncertainty about scientific claims of threat imminence and threat severity can enhance trust in the source and thereby increase the desired behavioral responses toward risk mitigation (Frewer et al., 2002; Habicht, 1992; Johnson and Slovic, 1995; Slovic, Fischoff, and Lichenstein, 1984). Several experiments also support this perspective (see Results). As such, some scholars have encouraged scientists to more openly include uncertainties when communicating to the public (Campbell, 2011; Leshner, 2003; Parascandola, 2000; Stocking, 2010).

In sum, research has produced a seemingly inconsistent body of evidence regarding whether, when, and why portrayals of uncertainty in science have generally positive, negative, or null effects. In 2003, Miles and Frewer summarized, “the literature indicates there are various arguments as to why communicating uncertainty is a positive activity, as well as why uncertainty should not be communicated, although there is little empirical evidence to support either view” (p. 268). Nearly 20 years later, there is much more empirical evidence but still a great deal of uncertainty about the effects of uncertainty.

The purpose of this review is to bring this literature into focus, to offer preliminary interpretations of potential patterns of effects, to apply a typology of uncertainty in science communication as a way of clarifying those patterns and thus possibly resolve some of the apparent inconsistency, and to provide directions for future research.

Framing

Framing selects “some aspects of a perceived reality and make[s] them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described” (Entman, 1993: 52). As such, frames can serve both as a persuasion technique and as an information accessibility mechanism (Shulman and Sweitzer, 2018) because they influence responses to a message by making related information or beliefs more available, accessible, or applicable (Chong and Druckman, 2007). Two fundamental message framing types are *emphasis* (highlighting a particular theme, interpretation, or aspects) and *equivalence* (using differently valenced or oriented content that is logically equal) (Cacciatore, Scheufele, and Iyenger, 2016). Uncertainty portrayals can function as emphasis frames, by highlighting a specific set of meanings and associations, and thus shaping interpretations and responses.

Uncertainty as Framing

Content analyses of public-facing science communication show that scientists and journalists frequently qualify their descriptions of scientific findings with portrayals of uncertainty (e.g., Rice et al., 2018; Ruhrmann, Guenther, and Kessler, 2015), using many variants that differ on all of the dimensions identified by van der Bles et al. (2019). These portrayals of uncertainty shape the intent and interpretation of sources and stated claims, predictions or hypotheses, and findings by coloring them in shades of ambiguity. Portraying uncertainty in a science communication message does not simply add a piece of information—it shapes the meanings, interpretations, implications, and schema activated regarding the ambiguity, imprecision, and confidence of the message and the messenger. As such, communicating uncertainty has been identified by scholars as a type of framing in science communication (Gustafson and Rice, 2019; Rice et al., 2018; Ruhrmann et al., 2015; Simis, 2013). Considering uncertainty as framing highlights its ability to shape the meanings and interpretations of a message (Entman, 1993; Jung, 2012) and influence the attitudinal and behavioral responses of the audience.

Myriad analyses across diverse media, locations, times, issues, and topics agree that public-facing science communication about specific scientific findings is often presented within an uncertainty frame via mentions of deficient knowledge, shortcomings of the research, controversy among scientists, and error or probability ranges (Antilla, 2005; Bailey, Giangola, and Boykoff, 2014; Jung, 2012; Kuha, 2009; Dispensa and Brulle, 2003; Painter and Ashe, 2012; Rice et al., 2018; Zehr, 2000). Uncertainty framing can also be manifested in broad public discourse trends like the "unsettled science" frame used as misinformation about climate science and tobacco research (Oreskes and Conway, 2011).

These varying forms of uncertainty portrayals in science communication are created by diverse forces, including good intentions such as journalistic ethical norms (Bennett, 1996; Boykoff and Boykoff, 2004), intended or unconscious influences such as insufficient science literacy or training, malignant motives such as public disinformation campaigns (Jacques, Dunlap, and Freeman, 2008; McCright and Dunlap, 2003; Oreskes and Conway, 2011), and the inescapable nature of uncertainty in science itself (Stocking, 1999).

Uncertainty Types

Making nuanced distinctions among distinct types of uncertainty is necessary for conceptual clarity, theoretical understanding, methodological consistency, and predicting audience responses. In large part, this is because different types of uncertainty represent fundamentally distinct uses, meanings, interpretations, and effects. For example, a portrayal of controversy within the scientific community has different connotations and implications than a portrayal of an estimated confidence interval in a model projection.

In the present review, we label the extant literature according to a typology of four types of uncertainty portrayals (deficient, technical, consensus, and scientific; Rice et al., 2018; Gustafson and Rice, 2019), so as to observe any patterns of effects across types. We choose this typology because of its parsimony, its ability to connect root causes of uncertainty to their associated communicative expressions, and because prior research has identified these types in real-world public science communication (Antilla, 2005; Rice et al., 2018; Zehr, 2000).

Deficient uncertainty. Uncertainty is often communicated by emphasizing a known gap in knowledge. These diverse "known unknowns" often exist because there is a lack of research on the question, or because that thing may not ever be known, or because the problem space has expanded (e.g., Kuhn, 2000; Rice et al., 2018; Zehr, 2000). For example, Jensen and colleagues (2008; 2011) operationalized uncertainty in this manner for their experiments by emphasizing known limitations of a study. Similarly, Gustafson and Rice's (2019) experiment operationalized deficient uncertainty in news articles about science findings with clauses such as "although much remains unknown and more research is still needed."

Technical uncertainty. Many scientific claims are limited by measurement error, modeling approximations, and statistical assumptions (Broomell and Kane, 2017). To account for this, and to promote transparency and accuracy, scientists frequently present findings as probabilities or as estimates couched in error ranges. This quantification of uncertainty is termed by Gustafson and Rice (2019; Rice et al., 2018) as *technical uncertainty*. To account for this, and to promote transparency and accuracy, science communication often portrays uncertainty as either a range (e.g., 7-15cm), as a probability (e.g., a 65% chance), or as an estimated value with a confidence interval or error bars (e.g., Morton, Rabinovich, Marshall, and Bretschneider, 2011).

Consensus uncertainty. The (un)certainty of any particular finding, theory, or prediction can also be described in terms of the collective discord/accord that exists about it – whether among relevant stakeholders (e.g., scientists, government officials) or within the body of evidence itself. Gustafson and Rice term this *consensus uncertainty*. This type of uncertainty is frequently employed as the manipulation in the experimental literature (see Results). The concept of consensus uncertainty is similar to colloquial uses of “disagreement,” “conflict,” or “controversy.”

Scientific uncertainty. All science is subject to the inescapable possibility that in the future, our current best understandings may change in ways that are currently unknown and possibly unknowable. These “unknown unknowns” are part of the reason that Popper (1961) said that knowledge is “tentative forever” (p. 280). As such, we can communicate uncertainty as an inherent feature of even the most confident scientific findings, because we do not know how future research, data, or theory will change how we view our current set of knowledge. The uncertainty type representing this epistemological principle is termed by Gustafson and Rice as *scientific uncertainty*. Frewer and colleagues (2002) found that focus group participants rated this type of uncertainty (“The information provided is the best available at present, but things may change in the future”) as being one of the most likely and the most acceptable causes of scientists’ uncertainty.

Methods

Criteria for Inclusion

This review assesses experimental tests of the effects of portrayals of uncertainty in public-facing science communication on individuals’ beliefs, attitudes, and behaviors. To be included, a study must portray uncertainty as an experimental manipulation, such that levels of outcome variables are compared between the condition(s) with messages using uncertainty and the condition(s) using a control message (no uncertainty). Non-experimental designs are excluded, such as focus groups and correlational surveys. Experiments were only included if the treatment message was about a science-related topic (i.e., a claim about evidence or predictions portrayed as made by scientists specifically or science generally). In addition, this review includes only studies using the context of public-facing mass communication (e.g., journalism, scientific reports, PSAs, communication campaigns) and thus excludes private, interpersonal, and/or informal communication contexts. The review is exclusively interested in persuasive effects on beliefs, attitudes, or behaviors (e.g., belief in the message, perceived credibility, behavioral intentions, risk perceptions), and thus we exclude experiments that instead measured effects on the correctness of message comprehension or interpretation. Further, this review only investigates tests of the effects of an uncertainty portrayal presented within a single message, and thus excludes studies where uncertainty was manipulated by presenting multiple or sequential separate messages. Lastly, this review focuses exclusively on verbal and numerical depictions of uncertainty, and excludes studies of the effects of visual depictions of uncertainty.

Search Procedure

We searched Google Scholar using the following terms: [uncertainty AND experiment AND “science communication”]. Then we repeated this search using, in turn, “ambiguous,” “ambiguity,” “controversy,” “conflict,” “imprecise,” “imprecision,” and “hedging” instead of “uncertainty.” Then, we repeated each of those eight searches using, in turn, “science,” “scientist,” “expert” and “communication” instead of “science communication.” For each of these 40 separate searches, we examined the first 200 items for peer-reviewed research (e.g., journal articles, book chapters, conference papers) that satisfied the above inclusion criteria (8x5x200 = 8,000 results). We set the cutoff at 200 items per search because Google Scholar orders the searches by relevance and, for nearly all searches, the results became mostly irrelevant around the 150th item. Then, lastly, for each individual item that fit the inclusion criteria, its entire reference list and Google Scholar’s entire list of subsequent works citing that study and cited by that study were inspected for additional studies that might also fit the inclusion criteria. This last step was repeated for each new inclusion until zero new inclusions remained. Thus, for a relevant publication to have been overlooked (aside from human coder error), it would have had to be not included in the 8,000 search results, to have cited zero of the 48 included studies, and also to have been cited by zero of the 48 included studies.

Coding

Table 1 presents the codes, values, and labels used to summarize the studies listed in Table 2. The first author coded the manifest and latent content, and consulted with the second author to resolve any ambiguities. More detailed coding definitions are available upon request.

[Tables 1 and 2 here]

Results

The search process resulted in a final set of 48 journal articles and book chapters, containing 68 separate experiments conducted on a total combined set of 38,947 participants. We provide a holistic interpretation of results that focuses on three key patterns across the included studies: a) negative, positive, or null main effects of the uncertainty manipulations, b) whether and how these main effects vary across the four uncertainty types, and c) when and how individual and contextual variables moderate the main effects of the uncertainty manipulations.

Effects by Direction: Positive, Negative, and Null

Negative effects. Several experiments found that communicating uncertainty had significant *negative effects*. For example, portrayals of uncertainty about vaccine safety can cause individuals to have greater doubts about vaccine safety and to perceive greater discord among scientists (Dixon and Clarke, 2013; Dixon et al., 2015). Similarly, participants exposed to contradictory research findings published in health news reported lower favorability ratings toward health research, lower perceived credibility of the research, and lower behavioral intentions toward healthy behavior (Chang, 2015). A sequence of several experiments by van der Bles and colleagues (2020) concluded that verbal (but not numerical) expressions of uncertainty slightly reduced participants' own levels of certainty as well as their trust in the message source.

Positive effects. Several experiments reported significant *positive effects* of communicating uncertainty. For example, Jensen (2008) reported that journalists and scientists are perceived as more trustworthy when they "hedge" reports of scientific findings with caveats or limitations. Similarly, Clarke et al. (2015) found that a hedging statement (although accompanied by information about the true weight of evidence) increased beliefs in scientists' certainty about the vaccine-autism controversy and decreased beliefs of scientific discord. Other research found that people with initial negative attitudes toward GMOs were more accepting of proposed GMO applications if the information contained statements about scientists' uncertainty (Frewer, Howard, and Shepherd, 1998). In the context of earthquake risk, trust in scientists was higher when a risk estimate included an explanation of the limitations of the estimate (Nakayachi, Johnson, and Koketsu, 2018). A news story about global warming resulted in higher perceptions of scientists' level of certainty when it stated the limitations of the study (Corbett and Durfee, 2004).

Null effects. Many experiments reported *no significant effects* of uncertainty manipulations. For example, a longitudinal experiment (Retzbach and Maier, 2015) operationalized "uncertain science" as a statement of both benefits and harms of nanotechnology, and showed it had no effect on beliefs or trust. Gustafson and Rice (2019) tested the effects of four uncertainty types across three different science topics, finding that three of the four uncertainty types had no significant effects on beliefs, risk perceptions, or behavioral intentions.

Effects by Uncertainty Types

Across these studies, the experimental manipulations of uncertainty stimuli vary widely, which may be a reason for the disparate findings of effects. Therefore, this section reorganizes the studies' results by the typology of *deficient*, *technical*, *consensus*, and *scientific* uncertainty.

Using the typology of four uncertainty types, the summary review (Table 2) indicates that portrayals of *consensus uncertainty* (i.e., disagreement, controversy) among scientists or within a body of evidence is the type of uncertainty most clearly associated with *negative* main effects (Table 2 row numbers 10, 11, 17, 18, 20, 21, 22, 24, 31, 32, 34, 35, 38, 39, 40, 44, 47). Importantly, Table 2 does not contain a single instance of consensus uncertainty resulting in positive main effects. Most of the extant findings of negative effects of uncertainty appear in experiments that used a form of consensus uncertainty as the uncertainty manipulation.

In contrast, the three other uncertainty types do not have consistent negative effects. This review finds no instances of *technical uncertainty* resulting in negative effects. Rather, technical uncertainty has often had positive main effects (1, 4, 12, 30, 42, 45, 46), positive effects moderated by individual-level trait variables, and null effects. *Deficient uncertainty* has been found to have a diverse mix of effects, including positive main effects (5, 9, 13, 18, 27, 42), negative main effects (18, 23, 34, 36, 41, 43, 48), null effects, and effects moderated by individual-level trait variables. While not studied frequently, *scientific uncertainty* has been found to have some positive main effects (2, 42), one instance of null effects (44), and one instance of negative effects (41).

Moderating or Conditional Variables in the Effects of Uncertainty

Table 2 also shows that the effect of the uncertainty manipulation is often dependent on individuals' level of a belief, attitude, or worldview variable (rows 2, 3, 5, 16, 19, 22, 25, 29, 30, 41, 46). This is sometimes even manifested in interactions where the effect of the uncertainty manipulation flips signs (positive or negative) depending on the level of the moderating variable. The following paragraphs summarize four key moderators of the effects of uncertainty portrayals.

Prior worldviews and prior topic opinions. Uncertainty may create especially fertile ground for confirmation bias and directional motivated reasoning (Nickerson, 1998; Taber and Lodge, 2006) because ambiguity, controversy, doubt, or imprecision *may inherently allow for* diverse interpretations (Chang, 2012, 2015; Jacques et al., 2008; McCright and Dunlap, 2003; Oreskes and Conway, 2011). For example, in the contexts of climate change and gun control, people tend to apply the most worldview-consistent interpretation of technical uncertainty (Dieckmann, Gregory, Peters, and Hartman, 2017). Several interactions noted in Table 2 follow similar patterns of confirmation bias and motivated reasoning. One example is a study (Nan and Daily, 2015) finding that portrayals of scientific disagreement regarding vaccine safety resulted in more supportive attitudes for individuals with prior support for vaccines, but less supportive attitudes for those with prior opposition to vaccines.

Trust in science and scientists. An individual's deference to, and trust in, science is associated with responses to science communication in general (e.g., Anderson et al., 2011; Lee and Scheufele, 2006). Table 2 indicates that these attitudes may drive responses to portrayals of uncertainty as well. For example, Binder and colleagues (2016) found that portrayals of technical uncertainty about nanotechnology resulted in lower perceived risk than portrayals of consensus uncertainty, but only for individuals who reported high deference to science. Similarly, Aklin and Urpelainen (2014) manipulated the degree of expert consensus (e.g., 60%, 80%, 98%) that was portrayed about environmental policy, and found that increases in consensus (i.e., more agreement) resulted in stronger policy support—but only for people who already had high trust in scientists. For those with low trust, the portrayals of higher consensus *decreased* policy support—a boomerang effect—possibly because it confirmed suspicions of systemic collusion.

Perceived role of uncertainty in science. Intuitively, opinions about the role of uncertainty in science seem to influence responses to portrayals of uncertainty. For example, people who see science as an ongoing debate that will always have inherent uncertainty responded more positively to uncertainty about climate change research, compared to people who see science as uncovering absolute truths (Rabinovich and Morton, 2012). Similarly, Johnson and Slovic (1995) found that individuals who believe technical uncertainty is a natural characteristic of good science communication expressed more positive evaluations of the science and scientists.

Topic. There is also some indication that the effects of uncertainty vary by topic. For example, Gustafson and Rice (2019) found some negative effects of consensus uncertainty in one topic (climate change) but not in two others (GMO food labeling and machinery hazards). In another study (excluded from the review's results per the criteria of uncertainty manipulations being contained in one message), uncertainty about dioxin in sewage sludge diminished credibility, but uncertainty about the reintroduction of gray wolves to populated areas increased credibility (Jensen and Hurley, 2012). In both studies, the authors invoke the theory of motivated information management (Afifi and Weiner, 2004) to argue that people may feel uncertainty about one topic is acceptable while similar uncertainty about a different topic is unacceptable.

Discussion

Summary of Results

To advance our knowledge of the effects of communicating uncertainty in public science communication, we conducted a systematic review of the experimental literature. Our interpretation of the extant literature focused on three elements: a) highlighting the sets of negative, positive, and null findings, b) observing substantially more consistent patterns of results after categorizing the experimental manipulations into four types of uncertainty, and c) identifying key moderators or contingencies of the effects of uncertainty portrayals.

Our review and summary observations reveal that portraying uncertainty in public science communication contexts has been found to have myriad positive and negative effects on a wide range of beliefs, attitudes, and behaviors. However, this cacophony of disparate findings can be somewhat clarified when separately examining the effects of four different types of uncertainty portrayals.

Specifically, experiments that used a form of *consensus uncertainty* (disagreement or controversy among experts or evidence) account for most of the extant findings of negative effects. In fact, our review found no instances of portrayals of consensus uncertainty with positive effects. There are multiple potential explanations for this consistent pattern of negative effects of consensus uncertainty. Some evidence indicates that people prefer ambiguity to conflict (Smithson, 1999), which may lead them to view the ambiguities implied by technical, deficient, and scientific uncertainty more favorably than the conflict implied by consensus uncertainty. Also, judgments are often made based on some weighted average of the opinions of experts (Budescu, Rantilla, Yu, and Karelitz, 2003), which suggests that portrayals of consensus uncertainty could affect judgments by influencing the perceived average of expert opinion. Similarly, consensus uncertainty is the only uncertainty type that provides direct evidence *contrary to* the claim, by implying that there are experts or evidence that take a contrary position.

For these reasons, portrayals of consensus uncertainty in public science communication may often result in negative effects.

In stark contrast, portrayals of *technical uncertainty* did not show negative effects—only positive or null effects. The effects of portraying *deficient uncertainty* are mixed, with several experiments finding positive effects and others negative effects. The effects of portraying *scientific uncertainty* are mixed but tentative because this type of uncertainty has rarely been studied.

This review also found that conditional effects are frequent. Further experimental research is needed to identify how and when the effects of communicating different types of uncertainty is moderated by individual and contextual factors (Fox & Irwin, 1998). The evidence from this review suggests influences such as motivated reasoning based on prior opinions about the topics, science, and scientists. However, it is important to note that the frequency of conditional effects found in the experimental literature is in large part determined by researchers' interests in conditional effects, and does not necessarily reflect the frequency, nature, or magnitude of conditional effects in the real world.

Limitations and Future Research

The findings of this review of the effects of uncertainty are themselves couched in uncertainties and limitations that could be reduced or improved by future research. One limitation to observations drawn from the current review is that of publication bias. However, the high frequency of null effects *despite* possible publication bias provides strong indication that we should not expect technical, deficient, or scientific uncertainty to have a strong pattern of significant effects in unpublished works. Another important limitation is that many of the included studies used very small samples, which are fertile ground for generating effects that do not replicate. It is important that we view those studies with appropriate skepticism (and uncertainty) when drawing conclusions about this body of literature.

Another relevant limitation is that the inclusion criteria or search methods may have excluded experiments that could help shine light on the question of the effects of uncertainty. Different methods may have resulted in a slightly different set of studies. It is also possible that relevant research might be siloed in other fields using very different terminology, and might neither cite nor be cited by the studies included here. It may be that more liberal inclusion criteria (such as including experiments in interpersonal or non-science contexts, and treatments involving multiple messages) would highlight additional or different patterns of results.

Similarly, applying a different typology of uncertainty types, or some other organizing mechanism, might unlock different or more helpful patterns of results. Future research could, for example, recategorize the uncertainties in these studies according to various other typologies (e.g., Funtowicz and Ravetz, 1990; Galesic, Kause, and Gaissmaier, 2016; Politi, Han, and Col, 2007; van der Bles et al., 2019; Van Der Sluijs et al., 2005). Although some of these frameworks do not focus specifically on characterizing communicative expressions of uncertainty (e.g., Funtowicz and Ravetz, 1990), they may still be very useful in highlighting additional or alternate dimensions of uncertainty and epistemology that could be helpful in understanding these phenomena.

Further, the multi-dimensional heterogeneities in characteristics (e.g., topic, stimuli, outcome variables, samples, year) of these 48 studies constitute potential confounds to conclusions drawn from this review. This caveat is particularly important given the evidence showing that responses to uncertainty are sensitive to contextual and individual characteristics. Two additional possibilities for future research include assessing the extent to which a) some topics are more frequently associated with some of the uncertainty types, and, if so, what aspect of the topic facilitates or emphasizes that type, and b) whether combinations or sequences of uncertainty types generate interaction effects.

Despite these limitations and uncertainties, the insights gained by this systematic review point to valuable recommendations for practice. Most importantly, public-facing science communicators can be encouraged that many uncertainties of science should not be shunned or swept under the rug. Rather, portrayals of deficient, technical, or scientific uncertainties can – and often do – engender positive or neutral responses from diverse audiences in diverse contexts. More specifically, communicators should feel confident in expressing technical uncertainty without fear of negative repercussions, but should be cautious about expressing consensus uncertainty unless it is appropriate to their context and goals. Overall, it is important to note that the negative effects of one type of uncertainty (e.g., consensus uncertainty) in one topic or to one audience do not imply that another type of uncertainty (e.g., deficient, technical, or scientific uncertainty) in another topic or audience also will have similar negative effects.

Conclusion

In order to advance additional practical recommendations for science communication, it is imperative that we conceptualize, operationalize, and interpret distinct types of uncertainty portrayals and their conditional effects with both rigor and nuance. Only then can we arrive at a consistent body of findings that illuminate consistent and generalizable patterns of effects of uncertainty in scientific discourse in the public sphere.

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Table 1

Codes for the Systematic Review

Column in Table 2	*Description*	*Labels and Values*
Order #	Order by year published	1-*k*
Author, Year	Abbreviated citation	Author(s), YYYY
Total N *(# exps)*	Total *N* of all samples (# of experiments)	# (#)
Sample Type	Type of sample	R = representative N = national, non-representative C = local adult convenience S = student/faculty convenience
Topic(s)	Topic of message(s)	e.g., “Climate,” “Nutrition,” “Vaccines,” “Assorted Science” (used when the stimuli presented uncertainty about multiple, disparate science topics)
Uncertainty Types	Type of uncertainty used as the treatment(s)	D = Deficient T = Technical S = Scientific C = Consensus
Main Effects	Main effects of uncertainty manipulation on outcomes	A = message-aligned attitudes or beliefs BI = message-aligned behavioral intentions Cr = perceived credibility of the message/source (e.g., trust, honesty, expertise, competence) EC = external certainty (perception of scientists’/experts’ level of certainty) IC = internal certainty (one’s own level of certainty) R = risk perceptions “+” = statistically significant positive effect (+R = heightened risk perceptions) “-” = statistically significant negative effect (-Cr = lowered credibility) ~~strike~~ = nonsignificant effect (~~IC~~ = nonsig. effect on internal certainty) *Note*: outcomes without notation (e.g., a plain “R”) indicate an interaction such that the effect is only significant at a particular level of a moderating variable. These are clarified in the Conditional Effects column.
Conditional Effects, Clarifications, and Caveats	Differences in effects across moderators, IVs, and DVs.	e.g., “T had a stronger +A effect in higher literacy individuals.”

Table 2

Experimental Tests of the Effects of Uncertainty in Public Science Communication

O#	*Author, Year*	*Total N (# exps)*	*S. Type*	*Topic(s)*	*Uncert. Type*	*Main Effects*	*Conditional Effects, Clarifications, & Caveats*
1	Johnson & Slovic, 1995	669 (3)	S	Chemical Hazards	T	+/-Cr, +R	sig (+) effect on R and trust; sig. (-) effect on expertise
2	Frewer et al., 1998	240 (1)	C	GMOs	S	+A	stronger +A effect among people with prior opposition
3	Kuhn, 2000	177 (1)	S	Environ. Hazards	D T C	~~A~~, R	prior env. concern moderated effects of C on perceived risk
4	Lipkus et al., 2001	169 (1)	C	Cancer Risk	T	~~Cr~~, -R	the message was intended to reduce risk perceptions
5	Corbett & Durfee, 2004	209 (1)	S	Climate Change	D C	+EC, +IC	D had sig. (+) effect on certainty rating, moderated by env. ideology
6	Wiedemann & Schutz, 2005	330 (2)	S	Electromag. Fields	C	~~A~~, ~~R~~	
7	Wiedemann et al., 2006	639 (1)	S	Electromag. Fields	C	~~Cr~~, +EC, ~~R~~	C had sig. (+) effect on perceived status of scientific knowledge
8	Dean & Shepherd, 2007	159 (1)	C	GMO Food Risk	C	~~Cr~~, R	C had sig. (+) effect on R when C involved government agencies
9	Jensen, 2008	601 (1)	S	Cancer Research	D	+Cr	sig (+) effect on trust; nonsig. effect on expertise
10	Corner & Hahn, 2009	99 (1)	S	Astronomy	C	-IC	
11	Gollust et al., 2010	598 (1)	R	HPV Vaccine	C	-A, ~~BI~~	the effect on BI was only tested in an underpowered subsample
12	Han et al., 2011	240 (1)	C	Cancer Risk	T	+A, ~~Cr~~	T had sig. (+) effect on cancer-related worry but not risk perceptions
13	Jensen et al., 2011	1082 (1)	S	Cancer Research	D	A, ~~Cr~~	D had sig (-) effect on fatalism, no effect on backlash or skepticism
14	Morton et al., 2011	208 (2)	S	Climate Change	T	BI	T had sig (+) effect on BI in gain frame conditions
15	Longman et al., 2012	120 (1)	S	Med. Side Effects	T	Cr, R	T only had sig. effects in the highest uncertainty (range) level
16	Rabinovich & Morton, 2012	214 (1)	S	Climate Change	T C	BI	interaction with prior belief about role of uncertainty
17	Dixon & Clarke, 2013	320 (1)	S	Vaccines	C	-BI, -EC, -IC	
18	Markon & Lemyre, 2013	434 (1)	N	Tap Water Risk	D C	-Cr, +BI, ~~R~~	C had sig. (-) effects on source trust, D had sig. (+) effects on BI
19	Aklin & Urpelainen, 2014	3331 (2)	N	Environmental Policy	C	+/-A	direction of effect dependent on prior trust in scientists
20	Chang, 2015	120 (1)	S	Healthy Behaviors	C	-A, -BI, -Cr, -IC	
21	Clarke et al., 2015	197 (1)	S	Vaccines	C	~~Cr~~, -EC, ~~IC~~	
22	Dixon et al., 2015	371 (1)	S	Vaccines	C	-A, -EC	-A effect is greater in individuals with prior opposition
23	Kimmerle et al., 2015	179 (1)	S	Neuroscience	D	-IC	
24	Kortenkamp & Basten, 2015	247 (3)	S	Assorted Science	C	Cr, -EC, -R	C had sig. (-) effect on perceived journalists' bias

25	Nan & Daily, 2015	338 (1)	S	Vaccines				C	+/-A	direction of effect dependent on prior support for vaccines
26	Retzbach & Maier, 2015	945 (1)	N	Nanotechnology				C	~~A~~, ~~Cr~~	
27	Thiebach et al., 2015	78 (1)	S	Assorted	D				+A, ~~Cr~~	A = perceptions of message as scientific
28	Winter et al., 2015	78 (1)	C	Video Game Effects				C	~~A~~, ~~Cr~~	
29	Binder et al., 2016	243 (1)	S	Nanotechnology	D			C	~~IC~~, R	when high deference to science: D had +R effect, C had -R effect
30	Joslyn & LeClerc, 2016	1833 (2)	CN	Climate Change		T			+A, +Cr	in one experiment, T had +Cr effect only among “doubters”
31	Koehler, 2016	393 (1)	N	Economic Issues				C	-A, -EC	
32	Kohl et al., 2016	352 (1)	S	Cognitive Science				C	-EC	
33	Sladakovic et al., 2016	147 (1)	S	Med. Side Effects		T			~~A~~, ~~BI~~	
34	Broomell & Kane, 2017	598 (2)	N	Psychology Research	D			C	A, -EC	D had sig. (-) effect on EC, C had sig. (-) effect on Cr and A
35	Dunwoody & Kohl, 2017	759 (1)	N	Pharma Pollution				C	-EC, -IC	
36	Flemming et al., 2017	218 (1)	S	Neuroscience	D				-IC	
37	Jensen et al., 2017	880 (1)	C	Cancer Research	D			C	-A	D had nonsig effects, C increased backlash and prevention fatalism
38	Johnson, 2018	2619 (1)	N	Assorted Science				C	~~A~~, ~~Cr~~, -EC	
39	Cook et al., 2017	714 (1)	R	Climate Change				C	~~A~~, ~~Cr~~, -EC	C had sig. (-) effect on EC, but can be eliminated via inoculation
40	van der Linden et al., 2017	2167 (1)	R	Climate Change				C	~~A~~, -EC	C had sig. (-) effect on EC, but can be eliminated via inoculation
41	Han et al., 2018	2701 (1)	R	Vaccines	D		S		-A, -Cr, -R	D and S had sig. (-) effects, stronger among those with high literacy
42	Nakayachi et al., 2018	750 (1)	C	Earthquake Risks	D	T	S		~~BI~~, +Cr, ~~R~~	D+S and T were two message factors. Both increased elements of Cr
43	Bott et al., 2019	787 (4)	N	Assorted Science	D				~~A~~, -EC	
44	Gustafson & Rice, 2019	2214 (1)	N	Assorted Science	D	T	S	C	-A, -Cr	C had some sig. (-) effects; but D, T, and S had no sig. effects
45	Howe et al., 2019	1174 (1)	R	Climate Change	D	T			+A, +Cr	T had sig. (+) effects; addition of D resulted in nonsig. effects
46	Joslyn & Demnitz, 2019	899 (2)	R	Climate Change		T			~~A~~, +Cr, +EC	Cr = trust; T had stronger effects in Republicans than Democrats
47	Nagler et al., 2019	1474 (1)	R	Mammography				C	-A	C also resulted in more negative emotional reactions
48	van der Bles et al., 2020	5633 (5)	N	Assorted Science	D			T	-A, -Cr, -IC	(-) effects were from D (verbal), not T (numerical)

Note: See Table 1 for explanations of labels and abbreviations.