

RESEARCH ARTICLE

JRST | WILEY

Conceptual contamination: Investigating the impact of misinformation on conceptual change and inoculation strategies

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Abstract

Misinformation has been extensively studied as both maliciously intended propaganda and accidentally experienced incorrect assumptions. We contend that “conceptual contamination” is the process by which the learning of incorrect information interferes, pollutes, or otherwise disrupts the learning of correct information. This is similar to a medical model of disease transmission wherein misinformation travels from person to person via multiple methods. And just as we can inoculate the public against diseases like smallpox or measles, we suggest this same approach (providing refutations to misconceptions that individuals may not have read yet) can inoculate the public from misconceptions. We sought to examine whether we could inoculate against misconceptions, and if so, would a refutation text outperform a more traditional expository text. We also sought to examine the role of emotions and attitudes. We randomly assigned 152 undergraduate

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students to one of four experimental conditions comparing both text type (refutation vs. expository) and text order (misconception first or second) on their ability to overcome misconceptions. Our findings indicate that reading refutation texts led to significantly fewer misconceptions and reduced negative emotions. We also illustrate that the prevailing approach to countering misinformation—providing expository support after exposure to misinformation—performed the worst overall. Our findings suggest that refutation texts continue to provide significant reductions in misconceptions, and that overall misconceptions can be reduced regardless of text type, if the correct information can precede misinformation.

KEYWORDS

attitudes, conceptual change, emotions, engagement, learning, refutation

1 | CONCEPTUAL CONTAMINATION

It is a very interesting time to be alive—having access to the internet grants one access to decades of research, and, through the advent of social media platforms, one can engage researchers in real time discussions. However, this access comes with a pretty significant catch—you have to navigate and locate these sources yourself, often without a guide, without being seduced by the myriad of articles designed to grab your attention through scary or misleading titles. This is made more difficult by mainstream news outlets showing “both sides” of an issue by having scientists debate with opinion columnists, sitting United States representatives using evidence from dubious sources to support their policy agendas, and the former president of the United States declaring The New York Times as “fake news.”

To complicate this journey, individuals may begin their search with a disadvantage in the form of misconceptions—through their previous experiences, they may believe or make inferences about incoming information that is scientifically incorrect. We should point out that while misconceptions are not ideal, even the most well-educated individuals have misconceptions—ranging from everyday experiences (how the seasons change, Mason et al., 2017; what artificial intelligence is, Antonenko & Abramowitz, 2023) to public policy decisions that can shape the health of future generations (whether to take action on climate change, Danielson et al., 2016), or if the government should ban research on Genetically Modified Foods (Heddy et al., 2017). One might hope that with such unbridled access to scientifically correct information, students (and adults) will be able to simply search about the topic they want to know more about, select the (scientifically) correct articles, read them, and shed their previous (mis)conceptions. However, that is not always the case.

Decades of research on conceptual change have shown us that when students have misconceptions about a phenomenon, simply presenting the correct information rarely leads to conceptual change (Danielson et al., 2016; Heddy et al., 2017; Sinatra et al., 2014; Sinatra & Hofer, 2016). Recently, refutation texts have shown remarkable promise in facilitating conceptual change by prompting the learner to actively integrate incoming information with prior knowledge (Danielson et al., *in press*; Schroeder & Kucera, 2022; Tippet, 2010). Refutation texts typically contain three important components—first, they state the inaccurate knowledge that the authors assume is held by the learner, then the text explicitly highlights this inaccurate information is incorrect, and finally, the text provides the correct information (i.e., Jacobson et al., 2021; Kendeou & O'Brien, 2014). For example, a refutation text might state, “It is incorrect to believe that human activity can have no impact on the climate. The climate can be changed by humans and is being changed by humans. In fact, almost all climate scientists (97%) agree that human activities that increase the amount of greenhouse gasses in our atmosphere have added to the greenhouse effect...” (Danielson et al., 2016, pp. 410–411). Across multiple studies examining socio-scientific topics (Danielson et al., 2016; Heddy et al., 2017; Jacobson et al., 2021; Jin et al., 2023; Trevors, Kendeou, et al., 2017; Trevors, Muis, et al., 2017), refutation texts routinely outperform expository texts to promote lasting conceptual change.

Many educators might also try to “get out in front” of these misconceptions by striving to present the scientifically accurate information first, as we also know it is more difficult to change learners' prior conceptions than to simply teach them the correct information (Ecker et al., 2022; Kendeou et al., 2013; Mason et al., 2017; Trevors, Kendeou, et al., 2017; Trevors, Muis, et al., 2017). Other attempts have been made at teaching students epistemic skills to better evaluate this misinformation (Tseng et al., 2021), and historical calls for updating “scientific literacy” are certainly not bound to the age of misinformation (Rudolph, 2024). However, misinformation travels extremely quickly online, and “getting out in front” may not always be possible (Osborne & Pimentel, 2023). As a recent example, ideas surrounding ways to protect oneself from COVID, or otherwise cure this disease, took many different shapes that could be extremely hard for an organization like the Center for Disease Control (CDC) to predict (and therefore refute). In order to better replicate this potential exposure to misinformation as experienced by those online, in the present investigation, we sought to examine the extent to which being exposed to the correct information, either before or after being exposed to misinformation, would influence the learning of correct information. We sought to extend this line of research by empirically contrasting a standard expository text (like one may find on the CDC website) with a refutation text to determine their impact on learning. Finally, contrasting the position of these interventions (refutation before or after misinformation) might illustrate under what conditions (pre or post-exposure) these interventions are most beneficial.

Finally, topics like COVID vaccinations do not occur in a vacuum—people might have strong emotions and attitudes around these topics as well. Previous research around facilitating conceptual change has examined the role that attitudes, emotions, and engagement play in learning about socio-scientific topics including climate change or genetically modified foods, for example (Danielson et al., 2016; Heddy et al., 2017; Jacobson et al., 2021; Trevors, Kendeou, et al., 2017; Trevors, Muis, et al., 2017). In the present investigation, we seek to expand our understanding of how attitudes and emotions impact learning about socio-scientific topics. In what follows, we discuss the current state of conceptual change research with a focus on one intervention in particular, refutation texts, as a way to promote conceptual change.

2 | LITERATURE REVIEW

2.1 | The case for conceptual contamination

In their 2009 article about general principles for learning, Alexander and colleagues briefly discuss that learning might be disadvantageous. They suggest that “Although the more positive and advantageous outcomes of learning are what may be sought, the learning system does not discriminate” (p. 179). While many teachers, parents, and science communicators have undoubtedly experienced this phenomenon, educational researchers mostly focus their research attempts around the more positive, scientifically aligned knowledge change. However, if we accept Alexander et al.’s (2009) assertion as true—that the learning system does not discriminate for content—then it stands to reason that learners can develop deep conceptual misconceptions around scientific content just as easily as creating more scientifically aligned understandings of content. We use the term *conceptual contamination* for this phenomenon, and below outline how this might come about when individuals engage with misinformation.

Misinformation has been extensively studied in isolation as both maliciously intended propaganda as well as accidentally experienced incorrect assumptions (Ferguson et al., 2012; Muis et al., 2015; Rapp & Braasch, 2014; Wardle & Derakhshan, 2017). Misinformation can range from relatively benign (e.g., that avocados are fruits and not vegetables) to extremely dangerous (e.g., the widely debunked but still shared claim linking vaccines to autism, DeStefano & Shimabukuro, 2019). There has been a marked uptrend in the number of researchers sounding alarms about the impact of misinformation (McIntyre, 2018; McIntyre, 2023; Sinatra & Hofer, 2021) and numerous calls (Lombardi & Busch, 2022; and discussions [Allchin, 2023; Feinstein & Waddington, 2020; Osborne & Pimentel, 2022]) around how we as educators can move forward in the “post-truth” era.

Defined as “any information that turns out to be false,” (Ecker et al., 2022, p. 13), misinformation is further distinguished from malinformation and disinformation. Specifically, malinformation is factually correct; however, this information is shared with the intent to cause harm (e.g., leaking personal medical information to undermine a political rival). In contrast, disinformation is both misinformation (information that is false) and also shared with the intent to either cause harm, to profit from its spread, or for other nefarious aims including causing instability or general confusion (e.g., spreading false medical information that will galvanize public support to revoke adding Fluoride to the water supply). Wardle and Derakhshan (2017) add to this definition by invoking the intent of the sharer. For example, misinformation is false and not intended to cause harm, disinformation is false and intended to cause harm, and malinformation is true and intended to cause harm. For clarity throughout the manuscript, we will utilize the term “misinformation” throughout to refer to information that is not factually correct (Lewandowsky et al., 2012).

We contend that “conceptual contamination” is the process by which the learning of incorrect information (by any means of transmission—print/online, conversation, television, radio, etc.) interferes, pollutes, or otherwise disrupts the learning of correct information. This is similar to disease transmission, wherein misinformation, like a virus, travels from person to person via multiple methods—whether through social media, television or talk radio, learner-sought-out websites, or simple exchanges in the barbershop or grocery store.

So, what can be done to confront the scourge of misinformation about science that is causing significant harm (even death) to those who fall prey to it? A popular approach to combating misinformation is to “prebunk” or “debunk”—essentially either try to warn individuals about

common misinformation ahead of time (before they encounter it), or try to correct that misinformation after they have been exposed to it. As Ecker et al. (2022) points out, “the most common type of correction is a fact-based correction that directly addresses inaccuracies in the misinformation and provides accurate information” (p. 18).

Similar to relating the spread of misinformation to disease transmission we can extend this analogy to virus inoculation. Just as inoculating the public against diseases like smallpox or measles involves providing them with a weakened form of the disease in question (and builds an increased resistance to the adverse effects of the disease), we suggest this same approach (providing refutations to misconceptions that individuals may not have read yet) can inoculate the public from misconceptions (see McGuire, 1961 and Fransen et al., 2023 for a detailed discussion). If this supposition holds true, presenting individuals with a scientifically accurate account should promote stronger learning outcomes and likewise “inoculate” the individual against misconceptions. There is some empirical support for this hypothesis. For example, Cook et al. (2017) highlight how presaging misinformation (in the form of presenting a falsely equivalent “both sides” argument to sow confusion, or highlighting how one could cherry-pick data) can function to neutralize the impact of misinformation. Lewandowsky and van der Linden (2021) highlight a number of inoculation (or “prebunking”) techniques (from general warnings to specific arguments) that can also minimize the effect of misinformation.

If prebunking is designed to inoculate against the spread of misinformation, then debunking can be thought of as a kind of treatment response to an individual currently exposed to misinformation. However, this approach assumes that the learner has been exposed to misinformation and currently holds misconceptions. Given the explanation of prebunking above, a refutational approach should function either as a form of prebunking or debunking, depending on the individual’s level of exposure. This is rarely explored empirically, and in the present investigation, we sought to control for this by altering the placement of the refutational text (before or after the misinformation) so as to explore if this intervention functions better as a prebunking or debunking strategy (or if there is no difference).

2.2 | Overcoming misconceptions with refutation texts

When individuals go online to educate themselves, they must contend with conflicting information scattered across multiple sources with dubious credentials. While searching for the “truth” about an issue, individuals may acquire a few misconceptions along the way. These misconceptions may include inferences about the world drawn from prior experiences. Inferences are compelling for the learning process, but when individuals’ prior knowledge is scientifically inaccurate, this can lead to incorrectly drawn inferences, inhibiting the learning process (Gregoire, 2003; Pintrich et al., 1993; Sinatra, 2005). For example, a student might have difficulty understanding thermal conductivity based on their previous experience with baking. When they open the oven, they might remember that touching the metal rack will burn them, but the air surrounding the rack does not. Therefore, they might infer that the air is a different temperature, when in fact both the air and rack are the same temperature. In the conceptual change literature, these incorrect inferences (and the structures that lead to incorrect inferences) are referred to as “misconceptions” (Posner et al., 1982; Strike & Posner, 1992). These conceptions arise from prior experience—including both physical interaction (like the oven above) as well as through language and explanations (like reading online search results or comments from social media)—and are generally intelligible and highly connected with other

knowledge structures but are scientifically incorrect and highly resistant to change (Posner et al., 1982). As access to information has expanded, so too has the burden of deciphering the veracity of this information and the assumptions it leverages.

Research has shown that when burdened with misconceptions, access to the correct information rarely leads to conceptual change, since most learners fail to recognize the discordance between correct information and misconceptions (Sinatra & Danielson, 2016). For example, while the public acceptance of human evolution is trending higher (with 2020 marking the first time more than 50% of Americans agreed), it is still significantly below the scientific consensus of 98% (National Center for Science Education [NCSE], 2021). This can also be seen in the perceived threat that global climate change poses. Most Americans would agree that climate change poses a major threat (54% of US adults), but there is a significant partisan divide (78% of those leaning democrat vs. 23% of those leaning republican). Additionally, *dealing* with climate change is seen as relatively lower priority (ranking 17th out of 21 topics) compared to issues like strengthening the economy or lowering healthcare costs (Tyson et al., 2023). As a final example, we need only look inward at the discussions about what types of inferences educational researchers can draw based on their research designs (Cook, 2001) or statistical analyses (Kraft, 2020).

Another approach would be to facilitate active processing and inference generation from the to-be-learned material and prior knowledge. Active processing and inference generation generally facilitates deeper understanding or comprehension (Ainsworth & Burcham, 2007; Graesser et al., 1994; Kintsch, 1988, 1992; Lorch Jr. & Van den Broek, 1997; McNamara et al., 1996). Thus, the question becomes, “How do we get learners to actively process information that may be in conflict with their prior knowledge, thereby undergoing conceptual change?”

In order for a message to promote conceptual change, it must be interpretable, originate from a credible source, explain the phenomenon in question, and be regarded as persuasive (Lombardi et al., 2013; Sinatra & Seyranian, 2015). “If the message lacks even one of these characteristics, change is unlikely to occur” (Sinatra, 2005, p. 110). The characteristics of the learner—their existing conception (is it strongly held, robust, and coherent?) and their motivation to learn about the content (are they dissatisfied with the products of their understanding, is the content personally relevant, are they in a social context which supports one stance over another?) interact with the content and design of the message to facilitate conceptual change. We recognize that multiple models of conceptual change exist, but we use Dole and Sinatra's (1998) model to illustrate two important points. First, conceptual change is a complicated process involving prior knowledge, motivation, social constructs, engagement, argumentation, and other constructs. Second, if the goal is to promote conceptual change, the design and content characteristics of the message are paramount. One way to leverage these characteristics is through the use of refutation materials.

Refutation materials are widely employed to facilitate conceptual change (Guzzetti et al., 1992; Sinatra & Broughton, 2011; Tippet, 2010). The advantage of refutation texts is thought to be derived from an explicit mention of assumed prior knowledge, which prompts the learner into recalling their prior conception at the same time as they process the new conception (Tippet, 2010). This co-activation of both models increases the probability that the learner will notice discrepancies between the two models (Kendeou & O'Brien, 2014). Typically, refutation texts adopt a three-part structure to achieve this co-activation: first, they state the common but inaccurate knowledge (humans are not influencing the climate), then they explicitly state that the previously mentioned knowledge is incorrect (however, most scientists believe

this is incorrect), and finally, they provide the correct knowledge (the Intergovernmental Panel on Climate Change, a group of scientists from around the world, have been publishing extensively on this issue for decades, IPCC, 2022) (Jacobson et al., 2021; Kendeou & O'Brien, 2014). This advantage over expository text has been shown across decades of research (Danielson et al., *in press*; Guzzetti, 2000; Schroeder & Kucera, 2022; Tippet, 2010; Zengilowski et al., 2022) and subjects including force (Kendeou & Van Den Broek, 2007), mathematics (Lem et al., 2017), and seasonal change (Cordova et al., 2014; Mason et al., 2017; Will et al., 2019), controversial science topics like climate change (Danielson et al., 2016), genetically modified foods (Heddy et al., 2017; Thacker et al., 2020; Trevors et al., 2016), and vaccinations (Kessler et al., 2019; Vaughn & Johnson, 2018), as well as public perceptions of history (Alongi et al., 2016; Donovan et al., 2018), public policy (Aguilar et al., 2019), immigration (Trevors & Kendeou, 2020), and dyslexia (Peltier et al., 2020).

While literature supports refutation texts as a viable intervention to counter misconceptions and promote conceptual change, we should note that change is not always easy or without discomfort. Humans are emotional beings, and the public outcry about Pluto's demotion to dwarf planet illustrates the extent to which emotions are invariably connected to learning and conceptual change. The demotion of Pluto resonated with many individuals around the world, and while some took to the streets in protest, others may have had their attitudes toward science shift to a more negative position (Tyson, 2009). Below, we briefly discuss the role of emotions and attitudes in learning and conceptual change.

2.3 | Attitudes, emotions, and their role in conceptual change

In addition to examining the impact of how information is presented to learners (e.g., refutational, persuasive, narrative, expository text), researchers have also examined how affective characteristics like attitudes and emotions might influence the conceptual change process (Broughton et al., 2013; Eagly & Chaiken, 1993; Lombardi & Sinatra, 2013; McGuire, 1985; Pekrun et al., 2007; Petty & Cacioppo, 1981; Sinatra & Seyranian, 2015; Zimbardo & Leippe, 1991). The attitudes and emotions that people feel about a topic have been shown to predict the extent of knowledge revision experienced (Heddy et al., 2017) and how they engage in higher order cognitive skills like computational thinking (Jiang et al., 2024).

Attitudes are defined as an overall evaluation of a person, event, or object (Eagly & Chaiken, 1993; Maio & Haddock, 2010). Attitudes are further operationalized as being on a valence of disliking to liking (Frey, 1986; Holbrook et al., 2005). Therefore, we define an attitude as a negatively to positively valenced evaluation of an attitude object. Attitudes have been shown to change (Eagly & Chaiken, 1993; McGuire, 1985; Petty & Cacioppo, 1981; Sinatra & Seyranian, 2015; Zimbardo & Leippe, 1991), which occurs when valence toward an attitude object becomes more negative or positive. Relevant to the current study, attitude change has been shown to predict conceptual change and thus is an important factor to measure when assessing conceptual change (Heddy et al., 2017).

Like attitudes, emotions have also been shown to be an important factor to consider in the knowledge revision process (Fiedler, 2000; Gregoire, 2003; Linnenbrink & Pintrich, 2002; Sinatra et al., 2014). We define emotions as a psychophysiological response to an aspect of the environment (Rosenberg, 1998). More specifically, we investigate epistemic emotions that are emotions that occur during the knowledge generation process, where the knowledge is the object that causes the emotion (Pekrun & Linnenbrink-Garcia, 2012; Trevors, Kendeou,

et al., 2017; Trevors, Muis, et al., 2017). Epistemic emotions are caused by congruity or incongruity between a learner's knowledge and the knowledge to be learned (Han et al., 2021). Thus, we investigate epistemic emotions related to conceptual change due to the congruity/incongruity that exists during the knowledge reconstruction process. These emotions can be either domain-specific (e.g., science, math; Pekrun, 2006; Pekrun & Stephens, 2010; Pekrun et al., 2006) or topic-specific (e.g., natural selection, climate change, and genetic modification; Pekrun & Stephens, 2012; Sinatra et al., 2014). Epistemic emotions are conceptualized as including positive (hope, pride) or negative (frustration, anxiety) valence (Pekrun, 2006). Additionally, they can be either activating (causing of psychophysiological arousal, enjoyment or anxiety) or deactivating (lack of psychophysiological arousal, relief, or boredom). In the present study, we explore the valence of emotions, but not their activation status. Emotional valence has been found to have a differential impact on learning and conceptual change (Fiedler, 2000; Gregoire, 2003; Heddy et al., 2017; Linnenbrink & Pintrich, 2002; Sinatra et al., 2014). Positive emotions have generally been found to have a positive relationship with conceptual change (Broughton et al., 2013; Heddy & Sinatra, 2013) and negative emotions have been shown to generally decrease as the extent of conceptual change increases (Heddy et al., 2017). For example, students learning about Genetically Modified Foods might initially have a misconception that these foods are dangerous, might cause illness, or are otherwise “unnatural.” These students might also hold negative views of science and scientists (since they created these foods in the first place). However, seeing a childhood television celebrity (Bill Nye, the science guy) publicly change their stance on GMFs (to align with general consensus that GMFs are generally safe, Klümper & Qaim, 2014) might prompt the learner to engage with the current research. This continued engagement might increase positive emotions (“these could enhance the lives of many”) and decrease negative emotions (“GMFs are not as scary as I thought”) thereby facilitating conceptual change.

Recently, there has been a call to include these more “hot” constructs in conceptual change studies. For example, in a recent review of the literature, Danielson and colleagues (Danielson et al., *in press*) highlighted that while there is a theoretical link between conceptual change and emotions and attitudes, they were unable to find a statistical relationship between refutation effectiveness and these constructs. However, they postulate that this might be due to a lack of statistical power, as only a handful of empirical articles reportedly measured these constructs. Given the relationship between emotions and conceptual change, we included emotions in our investigation of how misinformation influences the conceptual change process. We also seek to extend work (Heddy et al., 2017) that illustrates that these hot constructs can be viewed both as outcome measures as well as predictive measures.

In the present investigation, we sought to examine whether we could inoculate against misconceptions, and if so, would a refutation text outperform a more traditional expository text. We also sought to examine the role of attitudes and epistemic emotions. Our research was guided by the following questions.

3 | RESEARCH QUESTIONS

We designed the following research questions based on our previous research, search of the literature, and knowledge of conceptual change:

1. To what extent will text format (refutation vs. expository) and text order (before or after the misinformation text) influence conceptual change?

2. To what extent will text format (refutation vs. expository) and text order (before or after the misinformation text) influence epistemic emotions?
3. To what extent will text format (refutation vs. expository) and text order (before or after the misinformation text) influence attitudes?
4. Can we replicate the findings of Heddy et al. (2017) illustrating the relative impact of emotion change, knowledge change, and engagement on attitudinal change?

4 | METHODS

In the present research, we wanted to investigate the existence and prevalence of conceptual contamination and methods for inoculating the public against misinformation. We examined topics related to oral health for which the public holds widespread misconceptions. For example, the topic of adding Fluoride to the public water supply—a socio-scientific topic that, while controversial, is not as well-known as other topics (climate change, genetically modified foods). Furthermore, water fluoridation is an incredibly important topic due to the implications for public health and the extent of misinformation available online. That is, there are several online sources that can be found after a quick Google search that promote misinformation about the negative impacts of fluoridating public water sources. Recently, communities around the world are voting to no longer fluoridate their water supplies, which could have adverse health effects on members of those communities. These decisions are in direct contrast with the fact that the American Dental Association, the CDC, and the Environmental Protection Agency support the fluoridation of public water sources due to the proven health benefits of this practice. Scientific studies have shown that fluoridating water can significantly reduce dental disease. In fact, the CDC has voted water fluoridation as a top ten public health achievement in the history of the United States. Thus, these topics have widespread and important implications for health outcomes.

4.1 | Participants

One hundred and fifty-two undergraduate students enrolled in a preservice teacher education program at a large university in the mid-south region of the United States participated in the current study for extra credit. Student-reported demographics indicated 79% females, 81% White, with 80% of students reporting their age between 18 and 22. Students were recruited through class announcements and participation was voluntary. This study was certified as exempt by the University of Oklahoma Institutional Review Board.

4.1.1 | Design

This study follows a 2 (text-condition: expository with misconception text or refutation with misconception text) by 2 (text order: misconception text first or misconception text second) design, resulting in four experimental conditions. In this way, we could experimentally manifest and manipulate the order of science disinformation and conceptual change approaches to determine which approaches, if any, indicated significant advantages in resisting science misinformation and promoting successful conceptual change. Said another way, we wanted to

determine if there was a difference in prebunking vs. debunking, and whether an expository or refutational approach enhances any effect.

4.1.2 | Experimental materials

The measures used in this study include three experimental texts on Fluoride as well as measures of attitudes, emotions, knowledge, engagement, and demographics (see Appendix S1).

4.1.3 | Experimental texts

To recreate a typical online learning experience with conflicting information, we created three texts. We created a traditional expository text explaining what Fluoride is, where it is found, and the historical rationale of adding it to public drinking water. The *expository* text contained 1134 words and had an F/K grade level of 10.5. This base text was modified to create both a *misinformation* text (referred to here as the *contamination* text, 1796 words, F/K = 11.7), which contained false claims (abundantly available online) about water Fluoridation and its safety, and a *refutation* text (1305 words, F/K = 10.8), which contained both misconceptions and direct refutations of these misconceptions.

4.1.4 | Epistemic emotions

The Epistemic Emotions Scale was adapted from Pekrun et al. (2017) and contained 16 discrete emotions: Angry, Hopeful, Anxious, Bored, Curious, Happy, Fearful, Confused, Interested, Surprised, Frustrated, Hopeless, Excited, Worried, Enjoyment, and Pride. Based on previous research, surprise was conceptualized as a positive emotion (Heddy et al., 2017). Participants were asked to rate their emotions when thinking about Fluoridated water and responded via a 5-point Likert scale with 1 = “Not at all” and 5 = “Very Strong.” In the present investigation, two scales were created and deemed reliable (positive emotions: Cronbach's alpha = 0.804 pretest, 0.840 posttest; negative emotions: Cronbach's alpha = 0.875 pretest, 0.887 posttest).

4.1.5 | Attitudes about fluoridated water

The Attitudes about Fluoridated Water scale was adapted from Heddy et al. (2017) and contained four questions addressing the participants attitudes toward Fluoridated water. An example is “Adding Fluoride to water is beneficial to society.” Participants responded via a 5-point Likert scale with 1 = “Strongly disagree” and 5 = “Strongly agree.” This scale was deemed reliable (Cronbach's alpha = 0.959 pretest, 0.964 posttest).

4.1.6 | Knowledge measure

To measure the extent to which participants undergo conceptual change, a 20-item, multiple-choice knowledge measure was created to examine a participant's knowledge about Fluoride,

what it is, how it is created, and the health effects when ingested. Correct answers represented the current medical consensus, whereas incorrect answers represented common misconceptions about Fluoride (e.g., that Fluoride is created by scientists or is somehow unnatural). This scale was deemed reliable (Cronbach's $\alpha = 0.794$ pretest, 0.853 posttest).

4.1.7 | Conceptual Change Cognitive Engagement Scale

To measure the extent to which participants actively engage in the conceptual change process, the 27-item Conceptual Change Cognitive Engagement Scale (CCCES, Heddy et al., 2018) was used to determine the level of cognitive engagement participants reported during learning. Using a 5-point Likert scale, participants would report the degree to which they agreed with the following statement (1 = strongly disagree, 5 = strongly agree): "I was distracted by other thoughts while reading the text." This measure was found to be reliable (Cronbach's $\alpha = 0.865$).

4.2 | Procedure

After accepting the Informed Consent, participants completed the Attitudes questionnaire, the Epistemic Emotions questionnaire, and the Knowledge measure. Then, participants were randomly assigned to one of four experimental conditions: Contamination text followed by Refutation text (CR), Contamination text followed by Expository text (CE), Refutation text followed by Contamination text (RC), or Expository text followed by Contamination text (EC). After reading, participants completed the CCCES, the Attitudes questionnaire (again), the Epistemic Emotions questionnaire (again), the Knowledge measure (again), and a demographic questionnaire. They were then thanked for their participation and excused. The entire process took, on average, 20 minutes.

5 | RESULTS

5.1 | Preliminary/descriptive results

Preliminary analyses found no significant differences between any condition on age, gender, attitudes, positive emotions, negative emotions, or knowledge ($p > 0.05$) (see Table 1 for descriptive statistics by condition).

5.2 | Primary results

To answer our first research question, "To what extent will text format (refutation vs. expository) and text order (before or after the misinformation text) influence conceptual change?" we ran a 4 (Text condition: EC, CE, RC, and CR) by 2 (Time: Pre vs. Post) analysis of variance with repeated measure on the Time variable. Our analysis revealed both a significant main effect of time ($F(1, 148) = 300.8$, $MS_{\text{Error}} = 0.023$, $\eta^2 = 0.67$, $p < 0.001$), and a significant interaction between time and condition $F(3, 148) = 2.66$, $MS_{\text{Error}} = 0.023$, η^2

TABLE 1 Descriptive statistics by conditions.

	<i>N</i>	Age	Gender	Attitude	Positive	Negative	Knowledge
CR	30	23.4 (6.0)	25 (4)	3.26 (0.84)	2.10 (0.61)	1.96 (0.72)	0.35 (0.21)
CE	44	21.6 (3.4)	35 (8)	3.22 (0.89)	2.27 (0.64)	2.04 (0.75)	0.36 (/23)
RC	39	21.5 (3.0)	28 (9)	3.19 (0.98)	2.07 (0.62)	2.09 (0.82)	0.40 (0.18)
EC	38	24.2 (8.4)	32 (7)	3.32 (0.77)	2.40 (0.72)	2.13 (0.85)	0.36 (0.19)
Total	151	22.6 (5.6)	120 (28)	3.24 (0.87)	2.22 (0.66)	2.06 (0.78)	0.37 (0.20)

Note: Standard deviations are reported within the parentheses. The values that are outside of the parentheses are the raw means. For the “gender” variable, the values that are outside of the parentheses are the number of participants who self-reported as female, and the values that are within the parentheses are the number of participants who self-reported as male. Abbreviations: CE, contamination/expository; CR, contamination/refutation; EC, expository/contamination; RC, refutation/contamination.

squared = 0.05, $p = 0.05$. Specifically, all conditions illustrated significant learning gains from pre ($M = 0.37$, $SD = 0.20$) to post ($M = 0.67$, $SD = 0.23$), highlighting that no matter the order or text type, students were able to create a more accurate understanding of the phenomenon of water fluoridation. However, the interaction revealed that while there were no differences in knowledge by condition at pretest, simple effects tests revealed significant differences by condition at posttest. Specifically, students seeing the contamination text first followed by the expository text (CE condition) learned significantly less ($M = 0.59$) than both conditions containing the refutation regardless of position (CR condition $M = 0.70$, RC condition $M = 0.73$). These differences can be seen in Figure 1 and Table 2.

To answer our second research question, “To what extent will text format (refutation vs. expository) and text order (before or after the misinformation text) influence emotions?,” we ran two separate ANOVAs replicating the procedure above. Our analysis revealed no significant main effects ($F(1, 148) = 0.572$, $MS_{\text{Error}} = 0.156$, $\eta^2 = 0.004$, $p = 0.451$) or interactions ($F(3, 148) = 1.063$, $MS_{\text{Error}} = 0.156$, $\eta^2 = 0.021$, $p = 0.367$) for positive emotions (see Table 3 and Figure 2).

However, looking at negative emotions, we found both a main effect for time $F(1, 148) = 7.37$, $MS_{\text{Error}} = 0.28$, $\eta^2 = 0.05$, $p < 0.05$ and a nearly significant interaction between time and condition $F(3, 148) = 2.15$, $MS_{\text{Error}} = 0.28$, $\eta^2 = 0.04$, $p = 0.097$. Exploring this relationship further, we ran simple main effect tests to examine whether any differences were present between groups. Our analysis indicated that only the groups who encountered the contamination text in the second position (RC $M_{\text{change}} = -0.38$, EC $M_{\text{change}} = -0.25$) decreased their negative emotions ($p < 0.05$). This indicates that seeing the correct information first significantly reduced negative emotions. While this finding is exploratory in nature and should be interpreted with caution since it is outside of the traditional p -value range (Giner-Sorolla et al., 2024; Wilcox, 2017), this finding does align with previous findings that “getting out in front” of misinformation might have beneficial outcomes. These findings can be seen in Table 4 and Figure 3.

To answer our third research question, “To what extent will text format (refutation vs. expository) and text order (before or after the misinformation text) influence attitudes?,” we replicated the ANOVAs outlined above. Our analysis revealed a significant main effect of time, $F(1, 148) = 14.57$, $MS_{\text{Error}} = 0.43$, $\eta^2 = 0.09$, $p < 0.001$, indicating that attitudes increased from pretest to post test. We found no significant main effect for condition ($F(3, 148)$

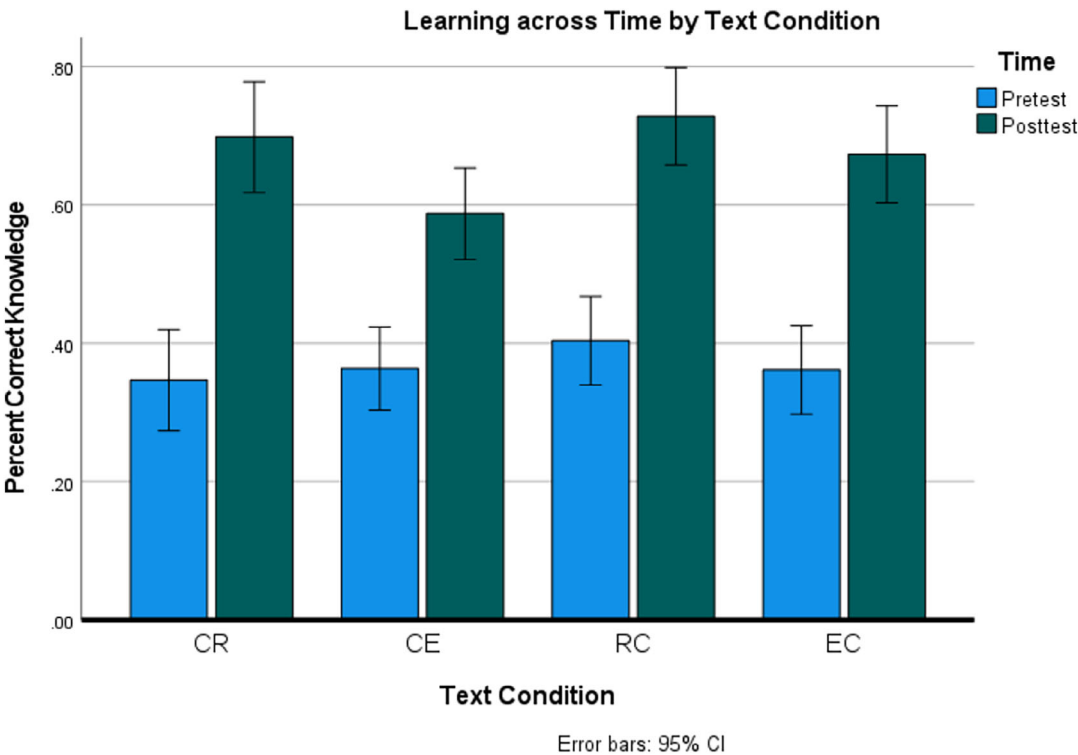


FIGURE 1 Bar chart for learning across time by text condition. CE, contamination/expository; CR, contamination/refutation; EC, expository/contamination; RC, refutation/contamination.

TABLE 2 Descriptive statistics for knowledge by condition and time.

Conditions	Pretest knowledge				Posttest knowledge			
	CR	CE	RC	EC	CR	CE	RC	EC
N	30	44	39	39	30	44	39	39
M	0.35	0.36	0.4	0.36	0.7	0.59	0.73	0.67
SD	0.21	0.23	0.18	0.19	0.16	0.24	0.21	0.25

Abbreviations: CE, contamination/expository; CR, contamination/refutation; EC, expository/contamination; M, mean; RC, refutation/contamination; SD, standard deviation.

= 0.497, MSerror = 1.24, eta squared = 0.010, $p = 0.685$), nor a significant interaction ($F(3, 148) = 1.031$, MSerror = 0.428, eta squared = 0.020, $p = 0.381$). Simple main effect tests indicate that only the groups who encountered the contamination text in the second position (RC Mchange = 0.47, EC Mchange = 0.35) significantly increased their attitudes ($p < 0.05$). This indicates that seeing the misinformation text first essentially suppressed an attitude increase, or, said another way, seeing the correct information first allowed for an increase in attitude, regardless of text type. These findings align with the results above and highlight what

TABLE 3 Descriptive statistics for positive emotions by condition and time.

Conditions	Pretest positive emotions				Posttest positive emotions			
	CR	CE	RC	EC	CR	CE	RC	EC
N	30	44	39	39	30	44	39	39
M	2.1	2.27	2.07	2.38	2.08	2.3	2.24	2.35
SD	0.61	0.64	0.62	0.72	0.78	0.65	0.64	0.79

Abbreviations: CE, contamination/expository; CR, contamination/refutation; EC, expository/contamination; M, mean; RC, refutation/contamination; SD, standard deviation.

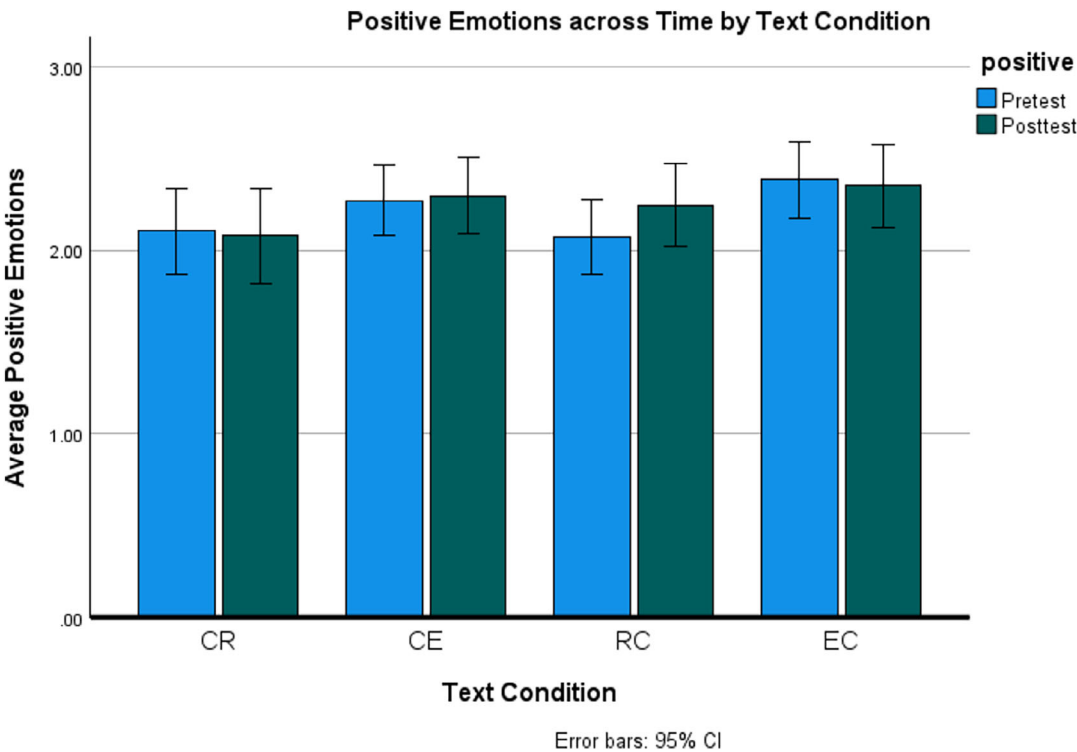


FIGURE 2 Bar chart for positive emotions across time by text condition.

many science educators and communicators would suggest—teaching students the correct information first can “buffer then against future misinformation” (see Figure 4 and Table 5).

Finally, to replicate the conceptual findings of Heddy et al. (2017), we conducted a regression analysis to predict the relative impact of emotion change, knowledge change, and engagement on attitudinal change. The regression analysis (Table 6) significantly predicted attitude change ($F(4, 146) = 21.31$, $MS_{\text{error}} = 0.53$, $p < 0.05$) and accounted for approximately 37% of the variance. Only positive ($B = 0.21$, $p < 0.01$) and negative ($B = -0.57$, $p < 0.01$) emotions were significant predictors of attitude change, with knowledge change close but not significant ($B = 0.11$, $p = 0.1$). Similar to Heddy et al., we found that a *reduction* in negative emotions was

TABLE 4 Descriptive statistics for negative emotions by condition and time.

Conditions	Pretest negative emotions				Posttest negative emotions			
	CR	CE	RC	EC	CR	CE	RC	EC
N	30	44	39	39	30	44	39	39
M	1.96	2.04	2.09	2.1	1.95	2.02	1.71	1.85
SD	0.72	0.75	0.82	0.86	0.78	0.86	0.64	0.81

Abbreviations: CE, contamination/expository; CR, contamination/refutation; EC, expository/contamination; M, mean; RC, refutation/contamination; SD, standard deviation.

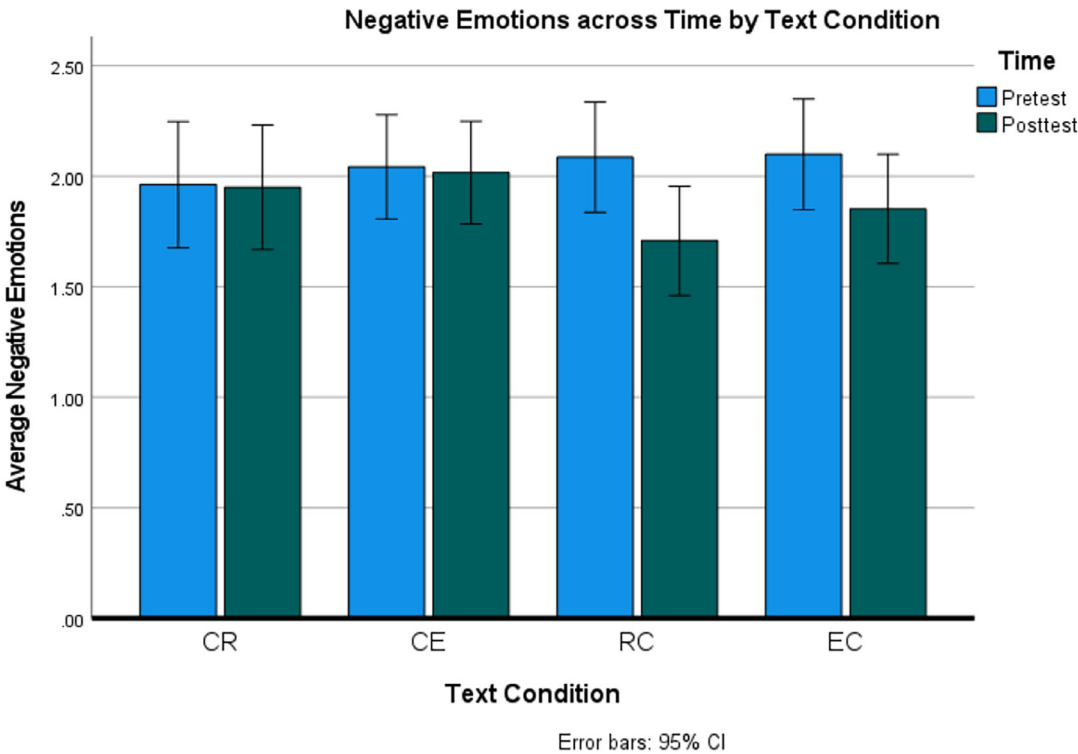


FIGURE 3 Bar chart for negative emotions across time by text condition.

the strongest predictor for positive attitude change. However, unlike Heddy et al., we found that an *increase* in positive emotions predicted more of the unique variance in attitude change than the variance predicted by knowledge change. However, it should be noted that all three variables were aligned with the direction predicted by Heddy et al. Interestingly, the CCCES failed to predict attitude change in the present investigation.

6 | DISCUSSION

In the present investigation, we found that text order was an important consideration for how learners build their understanding of the to-be-learned content. While all conditions learned a

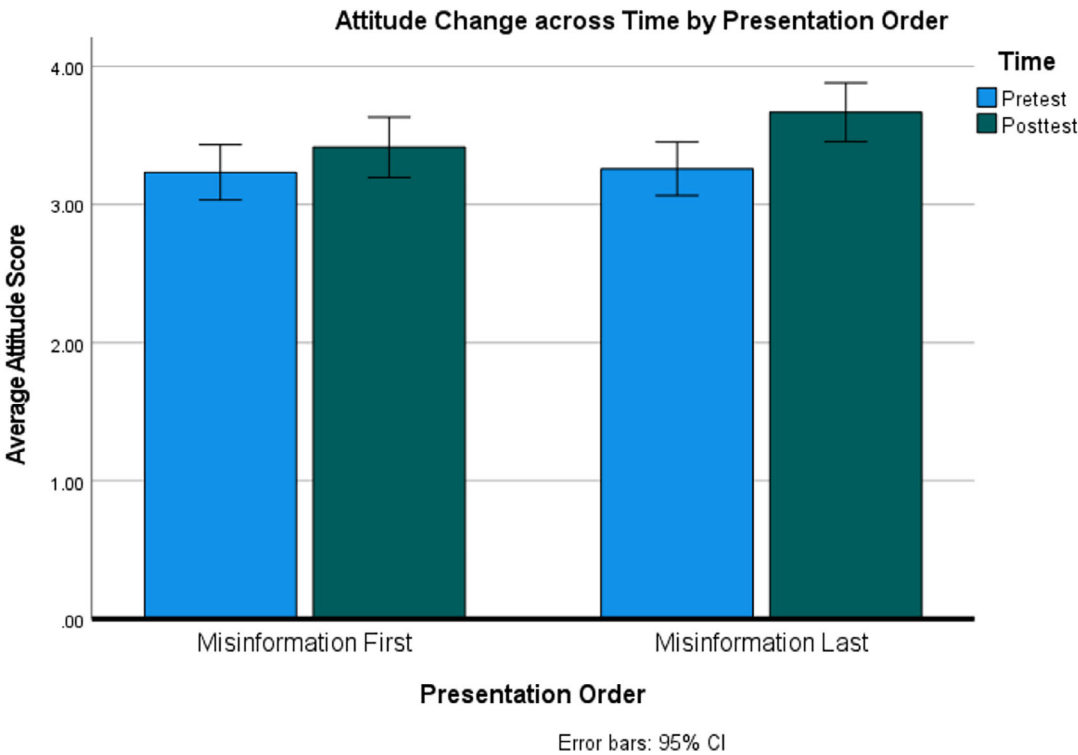


FIGURE 4 Bar chart for attitude change across time by presentation order.

TABLE 5 Descriptive statistics for attitudes by condition and time.

Conditions								
	Pretest attitudes				Posttest attitudes			
	CR	CE	RC	EC	CR	CE	RC	EC
N	30	44	39	39	30	44	39	39
M	3.26	3.22	3.19	3.33	3.35	3.46	3.65	3.69
SD	0.84	0.89	0.98	0.76	0.96	0.96	0.9	0.98

Abbreviations: CE, contamination/expository; CR, contamination/refutation; EC, expository/contamination; M, mean; RC, refutation/contamination; SD, standard deviation.

significant amount, those who saw the misinformation text first, followed by the expository explanation, performed the worst on the posttest measure of learning. We interpret this finding as that while, on average, college-aged individuals are able to parse through multiple conflicting texts and create a coherent understanding of the content, seeing the misinformation first prevented a significant amount of learning. Said another way, the standard approach many teachers, science communicators, and governments take to combat misinformation (by presenting the scientifically accurate information in an expository fashion presumably after an individual has been exposed to misinformation) seems to be the least effective.

TABLE 6 Regression results for the prediction of attitude change.

R^2	se	F	df_1	df_2	p
0.369	0.73	21.31	4	146	< 0.001
Variable	B	se	β	t	p
CCCES total	0.079	0.129	0.041	0.612	0.541
Knowledge	0.466	0.283	0.109	1.644	0.102
Positive	0.339	0.109	0.210	3.107	0.002
Negative	−0.688	0.081	−0.573	−8.543	< 0.001

Note: B, unstandardized coefficient; β , standardized coefficient; CCCES total, total score on the Conceptual Change Cognitive Engagement Scale; knowledge, knowledge change score; positive, change scores on positive emotions; negative, change scores on negative emotions.

This is an important finding in the era of misinformation. It was suggested by Sinatra and Danielson (2016) that science communicators engaged with evolution education should take a page from the climate science communicators' books and try to change the way they approach learners. We might echo that suggestion here by pointing to what we know is true in the public relations fields—controlling the narrative by making statements first and “getting ahead of the story” seem to be a more powerful approach than waiting for the story to break and reacting after the fact. This is a practice that has been shown to be effective for impacting public opinion on topics including the safety of sugar-sweetened beverages (Litman et al., 2018) and the safety of wireless 5G technology (de Vocht & Albers, 2022). For educators, especially in formal education, this might take the form of recognizing that these misconceptions are available to students and actively try to be the first voice that students hear. Our current results highlight that when students are shown the refutational text first—the text that explicitly mentions and refutes misconceptions, learners show an increased understanding and a decrease in negative emotions. This is a potentially important finding since we might expect that most students will encounter misinformation online—in a similar fashion as most students will encounter viral pathogens as they go about their days. And just like exposure to vaccines might inoculate students against viral infection (or simply reduce the severity of the infection), prebunking efforts might function to inoculate students against the negative impacts of misinformation (Ecker et al., 2022; Kozyreva et al., 2022; Lewandowsky et al., 2020). Expanding on these findings, we might suggest that formal educators consider adopting refutational approaches and strive to be the first voice learners experience when it comes to their content areas. It might be overly optimistic to think that educators will always arrive on the scene first, but it may be beneficial for educators to plan on this.

Of course, it would be more effective for science communications to reach learners first, but failing that, adopting a refutational approach seems to promote learning in either position. Given the findings of the present study, and supported by multiple meta-analyses that find the advantage of refutational approaches over more traditional expository texts (Danielson et al., in press; Guzzetti et al., 1993; Schroeder & Kucera, 2022; Tippet, 2010), we strongly urge science communicators and practitioners to consider adopting refutational approaches. We recognize that many educators might feel resistant to include information that is not factually correct (misconceptions) into their teaching or communication practices. However, we liken this resistance to the resistance some might feel about injecting antigens (in the form of vaccines) into their system to improve their immune response. Since teachers cannot realistically control

whether they reach their students first, they can control their method of engagement, and either as a prebunking or debunking strategy, refutational approaches have consistently outperformed their “just the facts” expository counterparts (Ecker et al., 2022; Lewandowsky et al., 2020).

We found further support for the role of emotions. Our results support the idea that science communicators should try to get out in front of misconceptions and that by doing so can significantly reduce the negative emotions around these socio-scientific topics. And while we did not find a significant interaction, the effect of the refutation text was similar to that in Heddy et al. (2017). It should be noted that both the positive and negative emotions expressed in this study are not very high to start out with, which may be different depending on the topic of study (e.g., climate change or genetically modified foods). Another intriguing finding is that students who received the contamination text first did not show an increase in their negative emotions, but rather, it was the conditions with the contamination text in the second position that showed a *decrease* in negative emotions. This finding is curious, as we might have speculated that exposure to misinformation might kindle an increase in negative emotions. However, these findings are potentially underpowered and need to be replicated. This potential decrease also suggests that further research is needed around the role of emotions, and we note that in the present study emotions were, across all conditions, rather low.

We found initial support indicating that refutation texts do more than simply prompt learners to keep both ideas in mind, but rather, leverage attitudes and emotions as well. And while our analyses did not reveal significant differences between these groups (which we discuss below), the analyses *did* reveal that the process of change looked different between these groups. Additional studies are required to dive deeper into this process, but we feel these results echo those found by Heddy et al. (2017), highlighting the importance of recognizing the role attitudes and emotions play in the conceptual change process.

An important finding in our study was that the mechanisms that facilitated attitude change were different for refutation and expository texts. The results provide evidence that when learners read a refutation text, they engage in conceptual change, which leads to the reduction of negative emotions, and an increase in positive attitudes toward the topic. The same result was not found for the expository text group. Therefore, the findings suggest that refutation texts facilitate change in such a way that emotions and attitudes are impacted, likely due to the direct refutation of misconceptions. Lombardi et al. (2016) found similar results albeit on a different topic—that refutation texts prompted learners to engage with the material in a different way than their expository counterparts—specifically, that those seeing the refutational text engaged in critical evaluation whereas those seeing the expository text relied more on their prior knowledge.

6.1 | Implications

Our study has implications for theory, research, and practice. Theoretically, our results further strengthen the prebunking notion that the learners' initial readings may be more influential in their understanding than subsequent readings, and therefore teachers/practitioners and science communicators should strive to inoculate the public by being the first on the scene (Villanueva Baselga et al., 2022). There have been relatively few studies that examine the empirical differences between debunking and prebunking, and while our study extends the theoretical implications in this matter, we ponder whether refutations are bound to the context in which they are experienced. Said another way, a refutation may function as either a prebunking strategy (if the

learner has not experienced the misconceptions), a debunking strategy (if the learner has experienced the misconception), or potentially *both a prebunking and debunking strategy* (if the learner has experienced some but not all of the misconceptions presented). Danielson et al. (2015) illustrated this bounding of text modifications when adding graphics to texts (with graphics exhibiting differential functioning), and we suggest more research is warranted to empirically determine if refutations exhibit similar differential functioning.

Regarding research implications, our study might suggest that future researchers examining misconceptions look to the order and magnitude of these misconceptions. Experimentally manipulating the order of misconception presentation might allow future researchers to determine how best to tailor messages for groups that may have yet to experience misinformation. For example, while we know that refutational approaches facilitate learning on discrete topics, what is the effect of multiple exposures to refutational texts? Would a refutational style of communication enhance epistemic and meta-cognition (how learners think about knowledge and their learning process), since refutational approaches encompass both of these aspects in their three-part structure? Additionally, while a significant amount of research has focused on whether refutational approaches are effective, we urge future researchers to move beyond this initial “are they effective” question to examine where they are most effective. Recent meta-analyses and systematic reviews (Danielson et al., *in press*; Guzzetti et al., 1993; Schroeder & Kucera, 2022; Tippett, 2010) have highlighted that, generally speaking, refutations outperform their expository counterparts. While the present investigation does not extend the “do refutations work?” line of research, it does extend the “when, for whom, and under what conditions” line of research that should come next. While the outcomes of the present study are modest and the effect sizes small, we hope these more nuanced manipulations around refutation texts provide inspiration for future research. For example, researchers may wish to examine different levels of refutations—refuting claims, arguments, or logical structures—to see which approaches are the most impactful. Are the impacts from time-delayed misconception exposure to expository or refutation text exposure similar or different to the present study?

Finally, for practitioners, we believe our implications are clear—consider adopting refutational approaches to your teaching or communication. As pointed out by Lewandowsky et al. (2020), misinformation is best dealt with preemptively (prebunked) and if not, debunked via direct refutations. Kozyreva et al. (2022) take this further, highlighting that in their 10 potential approaches in their toolbox of misinformation interventions, refutational approaches are featured prominently (40% of the interventions include refutational approaches). Finally, both Lewandowsky et al. (2020) and Kozyreva et al. (2022) point to the fact that “backfire effects”—effects that can cause students to either adopt a new misconception or strengthen an existing one—are both elusive and difficult to replicate. Ecker et al. (2022) point to the fact that these effects are so rare as to not provoke hesitancy of leveraging refutational approaches in practice.

6.2 | Limitations and future directions

All studies have limitations, and this study is no different. First, we recognize that the students who took part in this experiment are preservice teachers and not necessarily representative of the population of voters in the United States. However, we suggest that more research on preservice teachers should be conducted since they represent future teachers, and teachers are typically on the “front lines” of national debates like climate change or evolution (National Center for Science Education, 2021). Second, we recognize that our study includes only a single topic

and utilizes a pretest/posttest design. While the refutation literature has been criticized recently by overly relying on these approaches (Zengilowski et al., 2022), we suggest that the insights supplied here allow future researchers to replicate and expand on our methodology. Finally, we recognize that there was no main effect for refutation text; however, we believe this adds to the nuanced refutation text literature. We suggest that while refutation texts have proven effective across a wide variety of interventions, it is neither a panacea nor a one-size-fits-all approach.

In line with Zengilowski et al. (2022), we suggest that future researchers investigate both multiple topics (climate change, GMOs, vaccines, etc.) and multiple experimental formats. Utilizing within-subject designs will increase the time of participation, but we believe adding multiple topics/formats will also bring more ecological validity to many of these online experiments. Many individuals read multiple news articles in one sitting, browsing their local online newspaper or social media feed, for example. We also suggest that researchers seriously consider “warmer” variables including interest, emotions, and attitudes, as these variables may suggest whether learners would be willing to re-engage with these topics in the future, which might presage conceptual change even if it is not manifested in the current study. Finally, we recommend future researchers extending the timeline of studies to include delays of at least a week. We wonder if a single “one-shot” intervention like the one described in the current study is enough to truly facilitate conceptual change, or if multiple, repeated interventions over time would prove more impactful. While these questions are outside the scope of the current study, we believe these questions will have very intriguing answers and intend to pursue them in future studies. Finally, we acknowledge that some of the variables of interest (e.g., positive and negative emotions) in the present study may be utilized in roles other than being predictors or outcomes (e.g., moderators). However, this utilization was outside of the present study's scope. Therefore, we encourage future researchers to consider using these variables as moderators in their studies.

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How to cite this article: Danielson, R. W., Heddy, B. C., Ramazan, O., Jin, G., Gill, K. S., & Berry, D. N. (2025). Conceptual contamination: Investigating the impact of misinformation on conceptual change and inoculation strategies. *Journal of Research in Science Teaching*, 62(3), 629–654. <https://doi.org/10.1002/tea.21963>