

Overcoming Science Misconceptions: When is Refutation an Effective Tool for Knowledge Revision?

Claire E. Mason (clmason@ucsd.edu)
Department of Psychology, 9500 Gilman Dr
La Jolla, CA 92093 USA

Emma H. Geller (egeller@ucsd.edu)
Department of Psychology, 9500 Gilman Dr
La Jolla, CA 92093 USA

Abstract

Evidence from studies of knowledge revision show the refutation text is an effective tool for helping readers correct their inaccurate understandings. While refutation shows immediate benefits in group comparisons, it is unclear whether these benefits are restricted to particular retention intervals, if these benefits generalize across topics, or what predicts knowledge revision following refutation. In the present study, participants evaluated misconceptions across various science topics, then read a mix of refutation and expository texts and were prompted to rate their surprise and confusion after each text. Participants then re-evaluated the misconceptions immediately after reading the texts and again at a two-week delay. While both texts reduced misconception endorsement, refutation texts lead to a greater reduction in misconception endorsement on both the immediate posttest and at a two-week delay. Finally, exploratory analyses suggest participants' ratings of surprise predicted knowledge revision and partially mediated the effect of text type on knowledge revision.

Keywords: Refutation; knowledge revision; conceptual change; delay; surprise

Introduction

Many of us hold misconceptions about the world. We have theories or ideas that we believe to be true, but are inconsistent with scientific evidence. These misconceptions can be robust, can “feel” intuitively true, and can be resistant to instruction (Carey, 2000; Chi, 2005; Shtulman & Valcarcel, 2012). In educational settings, reliance on inaccurate prior knowledge can hinder students' future learning (Carey, 2009; Chi, 2005; Guzzetti et al., 1993). More broadly, reliance on inaccurate information has been shown to have problematic consequences for people's judgements and decision making (e.g., Lazer et al., 2018; Rapp & Salovich, 2018; Salovich et al., 2022). As such, an ever growing body of work seeks to understand when and why people revise their inaccurate knowledge, and what tools might support or facilitate knowledge revision (Braasch et al., 2013; Butterfuss et al., 2021; Chi & Roscoe, 2002; Danielson et al., 2016; Trevors & Kendeou, 2020).

A host of empirical studies have demonstrated that the refutation text can be an effective tool to help readers overcome their misconceptions (Broughton et al., 2010; Kendeou et al., 2014; Sinatra & Broughton, 2011). By design, refutation texts directly state the previously acquired

misconception, directly refute the misconception, then provide the relevant correct information (Guzzetti, 2000; Kendeou & O'Brien, 2014; Tippet, 2010). Refutation texts have typically been studied in contrast to expository texts, which provide the same relevant correct information as the refutation text, but do not discuss the previously acquired misconception (Tippet, 2010). In a typical refutation text study, participants 1) take a pretest, which indicates whether or not the misconception was endorsed before the text intervention, 2) read either a refutation or expository text, then 3) take a posttest, which indicates whether or not the misconception was endorsed after the intervention. Such experiments typically demonstrate that participants are less likely to endorse the misconception on the posttest as compared to the pretest, and refutation is more likely than exposition to reduce inaccurate beliefs at posttest (Diakidoy et al., 2016; Donovan et al., 2018; van den Broek & Kendeou, 2008).

There is strong evidence that refutation is effective for knowledge revision on an immediate posttest, but studies exploring longer retention intervals have yielded mixed results (Zengilowski et al., 2021). Some findings suggest that the immediate benefits of reading refutation texts are maintained over time (Aguilar et al., 2019; Asterhan & Resnick, 2020; Broughton et al., 2010; Kowalski & Taylor, 2017). In contrast, others suggest that the initial observed benefits of refutation diminish over time, and misconception endorsement returns to pre-intervention baseline (Ferrero et al., 2020; Nussbaum et al., 2017; Peltier et al., 2020). Some of the differences in findings could be attributed to differences in retention intervals. Moreover, prior work has used different dependent variables to measure misconception belief, including, but not limited to, binary endorsements, open-ended responses, or multiple choice comprehension tests.

Another possibility of interest is that refutation has different long-term effects based on the topic domain or specific misconception being refuted. A recent review found that the majority of refutation text studies only used one topic per study and one set of texts (Zengilowski et al., 2021). When only one text/topic is used to study refutation, the ability to generalize any findings is inherently limited. While some existing work has tested the efficacy of refutation across multiple topics (Van Boekel et al., 2017; Kendeou et

al., 2014; Yazbec et al., 2019), further work is necessary in this domain to support the generalizability of these findings (Zengilowski et al., 2021).

Finally, while refutation is more effective than exposition across groups, refutation does not change every single participant's mind. To better understand when refutation is effective, the current study aimed to identify and test predictors of successful knowledge revision following refutation. Several accounts have offered mechanistic explanations for why refutation texts are more effective than expository texts in facilitating knowledge revision, pointing to activation of readers' prior knowledge (e.g., Alvermann & Hague, 1989; Tippett et al., 2010) and/or the cognitive conflict refutation creates (Lin et al., 2016). In contrast to exposition, refutation brings about co-activation of readers' inaccurate prior knowledge and the newly acquired accurate information, facilitating readers' identification of discrepancies between the misconception and accurate information (Kendeou & O'Brien, 2014; Kendeou & van den Broek, 2007).

In the current study, we do not differentiate between these mechanisms; rather we aim to identify predictors following from these proposed accounts. Specifically, we suspected that readers' feelings of surprise and confusion following refutation would predict successful knowledge revision. Perhaps when learners are confronted with information that contradicts their prior knowledge, feelings of confusion might map on to the experience of cognitive conflict. We also thought that when the learner discovers their knowledge is inaccurate, their expectations are violated, and they would experience surprise (Munnich & Ranney, 2019). The experience of surprise could result in additional attention devoted to the new, correct information, and subsequently strengthen the learner's memory for the new, correct information. This idea is consistent with previous work suggesting that when feedback is surprising it draws additional attention, which can support learning (Butler et al., 2011; Jacobson et al., 2022; Trevors et al., 2017; van Loon et al., 2015).

The Present Study

To reiterate, previous work has demonstrated the efficacy of refutation texts in promoting knowledge revision, but it is unclear whether the benefits of refutation generalize across topics, if these benefits persist beyond an immediate posttest, or what might predict successful knowledge revision following refutation. The purpose of the following study is to (a) assess the effectiveness of refutation texts relative to expository texts for correcting misconceptions across a variety of science topics, (b) assess whether or not knowledge revision persists beyond an immediate posttest, and (c) identify predictors of knowledge revision following refutation to better understand for whom refutation is effective. To do this, we examined participants' endorsement of various science misconceptions before reading refutation and expository texts, immediately after reading the texts, and at a two-week delay. This allowed us to examine whether

refutation is equally beneficial across various science topics, and, if so, how long these benefits would obtain. We additionally asked participants to rate their surprise and confusion immediately after reading each text. This allowed us to examine whether surprise or confusion might be significant predictors of knowledge revision following refutation.

Method

The preregistration for this experiment can be found at https://aspredicted.org/RNR_61Y.

Participants

We recruited 128 undergraduate students to participate in this study in exchange for course credit. We excluded participants who failed to fully complete both parts of the experiment, reported not being fluent in English, or reported looking up answers at any time during the experiment ($N = 33$). The final sample included 95 undergraduates (85 females, 6 males, 3 non-binary, 1 preferred not to say; $M_{age} = 20.73$ years).

Design

The experiment followed a 2 (text type) x 3 (test time point) within-subjects design. Participants read three texts in each of two text types (expository, refutation). They rated their endorsement of misconception statements at pretest, on an immediate posttest, and at a two-week delay. The assignment of misconception statements to condition (expository, refutation) was counterbalanced across participants, and all statements and texts were presented in a randomized order for each participant.

Materials

Misconception and Filler Statements. Six common misconceptions and six true filler statements about basic science topics were selected based on pilot data. Methods and results of the pilot study are available on OSF (<https://osf.io/8w4rb>).

Texts Each misconception statement had a corresponding refutation text and expository text. When possible, we used pre-existing refutation texts on science topics. However, most texts were constructed for this study. All texts were between 250-450 words and followed a typical refutation text format, where the common misconception was stated, directly refuted, then a scientifically accurate explanation was provided.

Expository texts and refutation texts were nearly identical. The only difference was the expository texts omitted the refutation statement in the first paragraph of the text. Thus the refutation text explicitly commented on the common misconception, while the expository text did not make this explicit statement. The full set of texts can be found on OSF (<https://osf.io/8w4rb>).

Misconception Endorsements Participants were asked to classify misconception statements as true or false and to rate

their confidence in their judgment on a Likert scale (1 - Random guess to 5 - Sure of answer).

Surprise and Confusion Ratings Participants self-reported their surprise and confusion immediately after reading each assigned text. Each was measured with a single 5-point Likert scale item: “How surprising was the information in the text?” (1 - Not at all surprising to 5 - Very surprising) and “How confusing was the information in this text?” (1 - Not at all confusing to 5 - Very confusing).

Procedure

Data for the study were collected in two separate sessions online via Qualtrics. In the first session, participants completed a misconception endorsement pretest where they rated their endorsement of six misconception statements (among six additional filler statements). Participants were instructed not to look up any information as they completed the endorsements. Next, participants read a total of nine texts in a randomized order: three texts in each of two text types (expository, refutation), as well as three expository filler texts. After reading each text, participants were prompted to make their surprise and confusion ratings. After participants finished reading all the texts, they completed the immediate misconception endorsement posttest. Participants did not have access to the texts they had previously viewed when making their posttest endorsements. Two-weeks after the first session, participants returned for the delayed posttest, where they completed the misconception endorsement a final time. As in the previous tests, participants did not have access to the texts they had previously viewed in the first session. Participants did not receive any feedback at any time during the experiment on the accuracy of their endorsements.

Results

Models

Data analyses were run using generalized linear mixed effect models (GLMM) to accommodate repeated measures and binomial data. We used the R package lme4 (Bates et al., 2015), with simple contrasts calculated using the R package emmeans (Lenth et al., 2019).

Analyses of misconception endorsement and endorsement change used a binomial distribution, and analyses of surprise and confusion ratings used a Gaussian distribution. All tests of fixed effects are nested model comparisons using Type III sums of squares, and thus are reported as chi-squares.

Mediation analyses were run using the R package lavaan (Rosseel, 2012) using the delta method (Ledermann & Macho, 2015). We report standardized β coefficients and standard error for each effect.

Misconception Endorsements over Time

Misconception endorsement data are summarized in Figure 1. We coded “True” responses as 1 (indicating endorsement of the statement) and “False” responses as 0. We first examined whether text type and time point predicted misconception endorsement. The GLMM included text type

and time point as fixed effects and participant and topic as random effects.

We find a main effect of time point, $\chi^2(2) = 55.50, p < 0.01$. Endorsement was highest at pretest ($M = 0.63, SD = 0.48$), and was significantly lower at immediate posttest ($M = 0.31, SD = 0.46; z = 10.83, p < .001$). At a two-week delay, endorsement was higher than at immediate posttest ($M = 0.37, SD = 0.48; z = -2.88, p < .001$), but delayed misconception endorsements were still significantly lower than pretest endorsements ($z = 9.26, p < .01$).

We found no main effect of text type, $\chi^2(1) = 1.67, p > 0.05$, but there was a significant text type x time point interaction ($\chi^2(2) = 11.80, p < 0.01$). At pretest, there were no significant differences in misconception endorsement between text types (Refutation: $M = 0.61, SD = 0.49$, Expository: $M = 0.66, SD = 0.47, p > .05$). At the immediate posttest, misconception endorsement was significantly lower for participants who had read refutation texts ($M = 0.21, SD = 0.41$) as compared to expository texts ($M = 0.40, SD = 0.49, z = 5.18, p < .01$). At the delayed posttest, endorsement in the refutation condition was significantly higher than at the immediate posttest ($M = 0.29, SD = 0.46, z = -2.72, p < .05$), but was still significantly lower than the expository group at delayed posttest ($M = 0.45, SD = 0.50, z = 4.17, p < .01$). There was no significant change in endorsement for the expository group between immediate and delayed posttest ($z = -1.48, p > .05$).

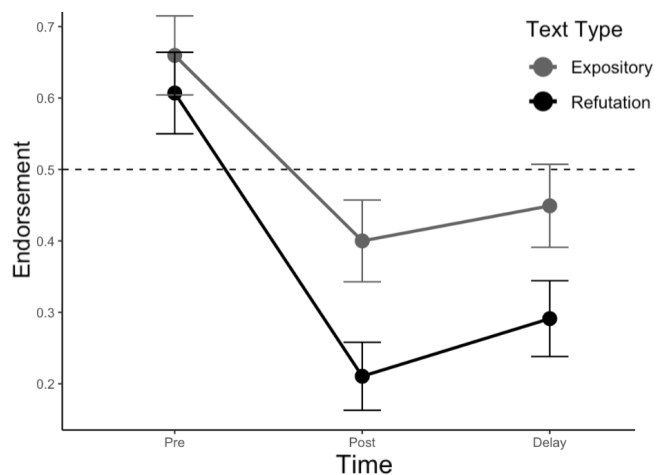


Figure 1: Misconception endorsements split by test time point and text type. Error bars represent 95% confidence intervals.

Differences by Topic

Our primary analyses were concerned with the efficacy of refutation across topics, and we treated topic as a random effect. However, we also wanted to explore if significant differences between topics emerged. In our data, the proportion of misconception endorsement varied across topics at different time points. Noticing variability between topics, we tested whether the benefits of refutation relative to exposition were consistent across topics. The GLMM included text type, time point and topic as fixed effects and

participant as a random effect. We find no significant three-way interaction between text type x time point x topic $\chi^2(5) = 1.08, p > .05$).

Effects of Confusion

To assess whether confusion might predict endorsement change, we first filtered endorsement responses to only include participants who inaccurately endorsed misconceptions at pretest. Next, we computed endorsement change scores by subtracting posttest endorsement from pretest endorsement. Thus endorsement change scores were either 0 (indicating no change in endorsement) or 1 (indicating a change in endorsement). We ran a GLMM with confusion rating as a fixed effect and participant and topic as random effects. We found confusion did not predict immediate ($\chi^2(1) = 0.38, p > .05$) or delayed endorsement change ($\chi^2(1) = 1.91, p > .05$).

Effects of Surprise

We repeated the same analytic approach to examine whether surprise might predict endorsement change. We found that surprise significantly predicted immediate endorsement change. We found a main effect of surprise ($\chi^2(1) = 23.13, p < 0.01$), where the log odds of revising the misconception increases by 1.06 for each one unit increase in surprise ($z = 4.81, p < .001$). Surprise also predicted long-term endorsement change. We found a main effect of surprise ($\chi^2(1) = 17.91, p < 0.01$), where the log odds of revising the misconception on the delayed posttest increases by 0.63 for each one unit increase in surprise ($z = 4.23, p < .001$).

Following the finding that surprise predicted endorsement change on both the immediate and delayed posttest, we next examined the possibility that surprise mediated the effect of text type. First, we confirmed that text type predicts immediate endorsement change. The GLMM included text type as a fixed effect and participant and topic as random effects. Indeed we found a main effect of text type ($\chi^2(1) = 25.61, p < 0.01$), confirming that participants were more likely to revise their misconception on the immediate posttest after reading the refutation text as compared to the expository text. We repeated this analytical approach to examine long-term endorsement change. We again found a main effect of text type ($\chi^2(1) = 22.42, p < 0.01$), confirming that participants who endorsed misconceptions at pretest were more likely to reject misconceptions at delayed posttest after reading the refutation text as compared to the expository text.

Next, we tested whether surprise mediated the effect of text type. First, we examined this with immediate endorsement change. The independent variable was text type, the mediator was surprise, and the dependent variable was immediate endorsement change. We find that text type was a significant predictor of surprise, $\beta = 0.60, SE = 0.13, z = 4.81, p < .001$. Moreover, when both text type and surprise were included in the model predicting immediate endorsement change, surprise was a significant predictor, $\beta = 0.07, SE = 0.02, z = 3.10, p < .001$, and the direct effect of text type on immediate endorsement remained significant, $\beta = 0.19, SE = 0.05, z =$

3.79, $p < .001$. These results suggest that surprise partially mediates the relationship between text type and immediate endorsement change (see Figure 2).

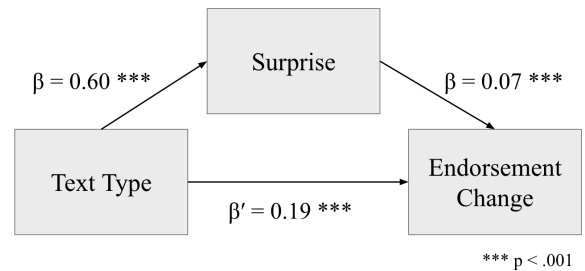


Figure 2: Surprise partially mediates the effect of text type on immediate endorsement change. All β s represent standardized regression coefficients.

We repeated this approach to test whether surprise mediated the effect of text type on long-term endorsement change. The independent variable was text type, the mediator was surprise, and the dependent variable was long-term endorsement change. We found that text type was a significant predictor of surprise, $\beta = 0.60, SE = 0.13, z = 4.81, p < .001$. Moreover, when both text type and surprise were included in the model predicting long-term endorsement change, surprise was a significant predictor, $\beta = 0.05, SE = 0.02, z = 2.49, p < .001$, and the direct effect of text type on long-term endorsement remained significant, $\beta = 0.21, SE = 0.05, z = 3.94, p < .001$. These results suggest that surprise partially mediates the relationship between text type and long-term endorsement change (see Figure 3).

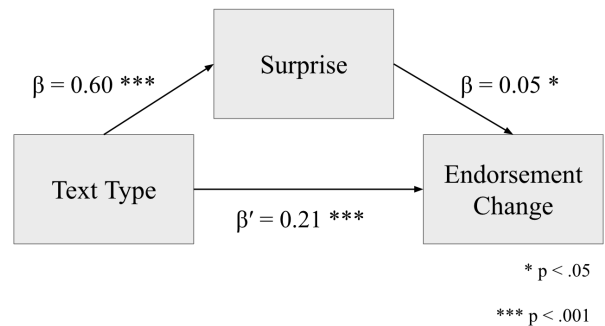


Figure 3: Surprise partially mediates the effect of text type on long-term endorsement change. All β s represent standardized regression coefficients.

Discussion

In this study, we explored the effect of refutation texts on knowledge revision across a variety of science misconceptions. We found that participants were significantly less likely to endorse misconceptions after reading refutation texts than expository texts, replicating previously demonstrated benefits of refutation texts relative to expository texts. After a two-week delay, participants were

more likely to endorse misconceptions than immediately following the text intervention, but these delayed endorsements still remained significantly lower than pretest. Endorsement of texts in the refutation condition was significantly lower than those in the expository condition at both posttests. Moreover, these effects did not differ significantly across misconception topics. Our results provide some evidence that refutation is effective across a variety of science topics and is not limited to particular misconceptions frequently used in the existing literature. They also suggest that the effects of refutation are relatively stable over a fairly long retention interval, showing a reduced rate of misconception endorsement (relative to expository texts) at a two-week delay.

While refutation unsurprisingly showed immediate benefits, we found that participants who read refutation texts still endorsed significantly fewer misconceptions at a two-week delay than at pretest. These misconception endorsement rates were, however, higher than endorsement rates at immediate posttest. The slight deterioration observed here though is unsurprising, given memory deteriorates over time. Participants in our experiment likely did not think about any of the concepts tested again during the retention interval, and our experimental design only included one exposure to the refutation. Thus we argue the finding that endorsement levels still remain below chance two weeks after reading a refutation is promising. We conjecture that repeated exposures could reduce the decline in refutation effects over time, which could be an important consideration for application in educational settings. Additionally, in the current study, we elected a two-week delay due to constraints around data collection and IRB approval, however exploring longer retention intervals remains an important and practically relevant avenue for future work.

Moreover, our findings broadly support the idea that refutation is effective across science topics. One identified limitation in the existing literature is that the majority of refutation text studies only examine one topic and use one text, calling into question whether or not the benefits generalize across topics (Zengilowski et al., 2021). In the present study, we examined the efficacy of refutation across six science topics, first accounting for topic as a random effect in tests of text type and then exploring variation in topic and whether it might moderate the effect of text type as a fixed effect. Our findings provide some support for the hypothesis that the benefits of refutation do not differ significantly different across science topics.

In our discussion of topics, it is important to note that in the current study, we only selected science-based topics, given we were primarily interested in correcting science misconceptions. Existing research on refutation texts is largely dominated by the benefits of refutation for non-controversial science topics. While some studies have demonstrated the benefits of refutation for historical knowledge (Donovan et al., 2018) and more socio-scientific issues (e.g., Heddy et al., 2017) refutation in these domains remains an understudied issue. Whether or not refutation is

beneficial for other domains, such as historical, socio-scientific, socio-political, and other controversial issues, presents an important avenue for further research in this domain. We conjecture that in these domains readers' emotions and different identity factors could exert a greater influence on whether or not refutation will effectively facilitate knowledge revision, presenting an intriguing issue for future work to explore.

Even in experiments that use non-controversial science topics, refutation does not change every participant's mind. In the current study, we aimed to identify predictors of knowledge revision in order to better understand when refutation is effective, specifically examining the role of surprise and confusion while reading refutation texts.

While we had hypothesized that participants' confusion might map onto the cognitive conflict that refutation creates, confusion was not a significant predictor of knowledge revision in the present study. We suspect that confusion may not predict knowledge revision because if participants were confused by the new correct information, they may have been less likely to rely on the new information provided in the text. However, it is also possible that our single-item Likert scale lacked the sensitivity to capture confusion and cognitive conflict. Future work could thus employ multi-item scales and behavioral measures (e.g., reading times, eye tracking) in order to provide greater insights into the role of confusion and cognitive conflict in knowledge revision.

In this study, we did find that surprise significantly predicted knowledge revision and partially mediated the effect of text type on endorsement change. People were significantly more surprised after reading refutation texts than after reading expository texts, and ratings of surprise predicted when people changed their minds. This suggests that refutation may be more effective than exposition at facilitating knowledge revision in part because refutation is surprising. Why might surprise predict knowledge revision? Similar to our expectations about confusion, we expected surprise might map on to the cognitive conflict participants experience while reading refutation texts. Indeed, participants found the refutation texts significantly more surprising than the expository texts. It would make sense that when refutation texts activate readers' inaccurate prior knowledge and then directly refute these beliefs that participants would experience surprise.

Prior work has demonstrated that surprising errors are more likely to be corrected (Butterfield & Metcalfe, 2001), and surprising feedback improves later memory (Fazio & Marsh, 2009). Such demonstrations have put forth the hypothesis that when feedback is surprising, people devote more effort and more attention to that feedback, and this enhanced attention in turn has a positive effect on memory (Fazio & Marsh, 2009). In the current study, it is possible when participants read refutation texts and experience greater surprise, they devote more attention to the text, which in turn benefits their memory for the correct information provided in the text. We propose this is a likely explanation for the partial mediation in the present study. This could be tested in future

work probing specifically for memory rather than endorsements, which probe belief. Finally, it is important to note that the current study finds surprise is a partial, but not full, mediator of the effect of text type, leaving open questions about additional cognitive or emotional factors at play. This partial mediation suggests that, while surprise is significant, something beyond just surprise is happening when refutation changes readers' minds. Considering and exploring what other factors in addition to surprise, including but not limited to attention, subject interest, and metacognitive monitoring, might mediate the effects of refutation then is a relevant future direction for research in this domain.

Conclusion

Scientists and educators alike have a vested interest in correcting science misconceptions and promoting accurate understandings. Refutation texts have been established as a powerful tool for addressing science misconceptions. The current study demonstrated that refutation texts effectively reduce science misconceptions across multiple science topics, and that their benefits persist at a two-week delay. It also provides evidence to suggest surprise has a role in facilitating knowledge revision following refutation. Tools designed to support or facilitate knowledge revision, including refutation texts, can be subject to limitations in their durability and or generalizability. Identifying the instances in which these tools effectively promote change contributes to existing theoretical understandings of knowledge revision processes and allows for thoughtful consideration as to how we might modify or enhance existing tools to improve their efficacy.

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