Contested Science: Individual-level insight into interpretation of evidence explains group-level polarization

Nadia Said^{*1,2}, Helen Fischer³ & Gerrit Anders¹

¹Interdisciplinary Center for Scientific Computing (IWR), Heidelberg University. Im Neuenheimer Feld 205, 69120 Heidelberg, Germany

²Department of Psychology, University of Tübingen. Schleichstr. 4, 72076 Tübingen, Germany

³Max Planck Institute for Human Development, Center of Adaptive Cognition, Berlin, Germany

*Nadia Said (corresponding author). E-mail: nadia.said@uni-tuebingen.de

Abstract

Societal polarization over contested science has increased in the recent years. To explain this worrisome trend, political, sociological, and psychological research has identified societal macro-phenomena as well as cognitive micro-level factors that explain how citizens reason about the science. Here we take a radically different perspective, and highlight the effects of metacognition: How citizens reason about their own reasoning. Leveraging methods from Signal Detection Theory, we investigated the importance of individual-level metacognitive insight for group-level polarization for the heavily contested topic of climate change, and the less heavily contested topic of nanotechnology. We found that, for climate change (but not for nanotechnology), increased insight into the accuracy of own interpretations of the available scientific evidence related to lower group-level polarization over the science. This finding held irrespective of the direction of the scientific evidence (endorsing or rejecting anthropogenicity of climate change). Furthermore, the polarizing effect of scientific evidence could be traced back to higher metacognitive insight fostering belief-updating in the direction of the evidence at the expense of own, prior beliefs. By demonstrating how individual-level metacognition links to group-level polarization, the present research adds to our understanding of the drivers of societal polarization over science.

Belief polarization, the tendency of individuals or groups to update their prior beliefs in opposing directions after observing the same evidence (Cook & Lewandowsky, 2016), has risen over the recent years (Campbell, 2018; Iyengar, Sood, & Lelkes, 2012; Pew Research Center, 2014; Webster, 2005; Zarkov, 2017). While belief polarization has long been observed in the context of issues of worldview such as immigration, multiculturalism or religion (Dixit & Weibull, 2007), citizens have recently become polarized over seemingly emotionless science. Research into the “widening gap”, for example, has demonstrated that, despite increasing scientific consensus, partisan polarization over climate change has increased among American voters since the late 1990s, and continues to do so (Dunlap et al., 2016; Dunlap & McCright, 2008). Similar polarization trends have been observed among the American public for stem cell research and human evolution (Drummond & Fischhoff, 2017), or vaccination (Schmidt et al., 2018). A multitude of research has identified societal macro phenomena and “mega trends” to reinforce societal belief polarization, such as the rise of the Internet and social media (Gabler, 2016; Sunstein, 2018), as well as micro-level cognitive factors such as prior beliefs about the science (Fryer et al., 2019; Jern et al., 2014; Kahan et al., 2017), and biases in information processing, such as confirmation bias (Del Vicario et al., 2017), or motivated reasoning (Hart & Nisbet, 2011). What these explanations, as diverse as they may be, have in common, is that they try to isolate drivers of how citizens reason *about the science*. That is, previous explanations were mostly concerned with object-level cognition, our reasoning about the subject matter itself. Here we take a radically different perspective, highlighting the importance of metacognition: How citizens reason about *their own reasoning*. That is, the present research illuminates the role of insight into the validity of our own thoughts. For example, on the object-level, citizens might reason that a novel piece of evidence about climate change is inaccurate because it contradicts own prior beliefs. On the metacognitive level, in contrast, citizens can take a step back, and reflect on how much their own reasoning about the evidence is distorted by prior beliefs, and hence lacking validity. Importantly, we explore whether such critical examination of own interpretations can directly affect group polarization: Does individual-level insight into the validity of own interpretations of the available evidence reduce group-level polarization over the science?

Metacognitive reflection on our thoughts can lead to enhanced humility about their validity: While object-level reflections take our interpretations of the world for granted, metacognitive reflections enable us to distance ourselves from our interpretations and recognize them as what they are, interpretations, and, consequently, as potentially incorrect (Frith & Frith, 2012). Such insight about the fundamental fallibility of our interpretations (that, ultimately our beliefs are built upon) may be a necessary precondition to be appropriately attentive to, and open for, belief-disconfirming evidence. Lacking insight into the validity of one's thought, in contrast, manifests itself in unjustified confidence in interpretations of the world, and can propel the psychological tendency to interpret evidence selectively such that it conforms prior beliefs. For instance, physicians holding unjustified confidence in their diagnosis tend to prematurely narrow down the field of alternative diagnoses, and even avoid searching for additional resources and diagnostic tests, or second opinions (Meyer et al., 2013). Unjustified confidence in own positions and judgments also tends to be enhanced in individuals holding radical political beliefs (Rollwage et al., 2018; Zmigrod et al., 2019), and lacking updating of confidence in one's beliefs after receiving corrective feedback is related to right-wing authoritarianism (Sinclair et al., 2020). Recent neuroscience research has identified modulated neural processing as a key mechanism behind confidence-driven effects in that higher confidence amplifies selective integration of confirmatory evidence, while confirmatory evidence is abolished (Rollwage et al., 2020). When citizens are confronted with information on politicized science, lacking insight into the validity of their interpretation of the evidence might hence foster the selective, belief-congruent interpretation of this evidence.

Critically, these individual-level effects could then prove a critical driver of group-level polarization over contested science: If citizens lacking metacognitive insight into their reasoning about the available evidence tend to update their beliefs in the direction of their prior beliefs, they should be a stronger driver of group polarization over the science. Conversely, if citizens with more accurate insight into their interpretation update their beliefs less in the direction of their prior beliefs, this should reduce group polarization. While previous research has investigated whether citizens have insight into their belief change (Wolfe & Williams, 2018), – that is, the *outcome*–, we investigated whether citizens have insight into their evidence interpretation, that

is, the *process*. This is a crucial distinction since being aware of the fallibility of own reasoning processes may enhance potential corrections of this process while still *forming beliefs*, as opposed to already having formed them.

We provided citizens with a range of summary texts providing scientific findings about climate change and nanotechnology. The texts varied the direction of evidence (a) the endorsement versus rejection of scientific consensus for the topic of climate change, and (b) the endorsement of benefits versus risks for the topic of nanotechnology. The absolute number of endorsement/rejection texts was equal within each topic, such that the provided evidence base was balanced. The topics of nanotechnology and climate change were chosen as they both constitute science topics that are contested, but to a different degree since nanotechnology constitutes a less contested topic compared to climate change (Cobb & Macoubrie, 2004; Drummond & Fischhoff, 2017). Hence, comparing climate change and nanotechnology in one study allows us to explore whether metacognitive insight as a driver a polarization depends on the degree of polarization of the science. The accuracy of citizens' interpretation of the texts was assessed ("This summary provides evidence that nanotechnology risks outweigh benefits", or "This summary provides evidence that human activity is not the cause of increasing temperatures"). Crucially, we also assessed the accuracy of participants' metacognitive insight into the validity of their interpretations of the evidence. To do so, participants indicated, after each interpretation: "How certain are you that your assessment is correct?" ("50%: I guessed" to "100%: I am certain"). This allowed us to quantify the degree of metacognitive insight citizens had into the validity of the interpretation of the evidence: Does insight into own distortion of evidence impact polarization over the science?

To sum up, we propose that metacognitive insight about the validity of our interpretations of evidence is recognizing that these interpretations may be incorrect, and can reduce group polarization over the topic in question.

Method

Participants. A total of $N = 354$ participants completed the experiment. Participants were recruited over Mturk, an online participants pool that provides samples that are reasonably representative of the general US population (McCredie & Morey, 2019). A total of $n = 189$ (53%) participants were female, and the average age of participants was 42 years (range = 21-75). Participants had a range of educational backgrounds (lowest school leaving certificate: 1%; middle school leaving certificate: 12%; highest school leaving certificate: 28%; Bachelor: 43%; Master or equivalent: 14% other: 0.8%).

Materials. Participants read several texts summarizing scientific evidence about the scientific topics of climate change and nanotechnology. The texts varied the *direction of evidence* as either endorsing or rejecting (a) the anthropogenicity of climate change (two texts endorsing, two rejecting¹), and (b) the benefits of nanotechnology, relative to its risks (four on benefits, four on risks). The texts on climate change were taken from previous research (Fryer, Harms & Jackson, 2019). The texts for nanotechnology were newly developed for the present study, and pre-tested by a sample of $N=49$ psychology students at Heidelberg University to ensure the displayed direction of evidence (endorsement vs. rejection) could be classified as intended. All texts were of approximately equal length (around 100 words each), comprehensible without expert knowledge, and consisted of three parts, providing: (1) a description of the study or general introductory sentence; (2) a summary of the results; and (3) the conclusions that can be drawn from the study. All summaries are provided in the Supplementary Material.

Procedure. We employed four different control mechanisms to ensure reliable and valid assessment. First, we only accepted Mturk workers with a 98% approval rating or above. Second, before entering the survey, participants completed a captcha to exclude potential bots. Third and fourth, we introduced three practice rounds that participants needed to complete before entering the main study. The practice rounds were completed on an unrelated topic (gluten sensitivity), and comprised (a) attention checks as well as (b) task comprehension checks.

1 For climate change, participants also read two neutral texts. Since these could not be rated as endorsement or rejection of anthropogenicity, however, they were excluded from the analysis.

The main study was completed in the following order for both topics (climate change and nanotechnology): (i) Prior beliefs; (ii) provision of each text summarizing scientific evidence, text-specific assessment of the (iia) interpretation of each text, and (iib) confidence in the accuracy of the interpretation; (iii) posterior beliefs; (iv) demographics (age, education and gender).

Order of the topics, as well as the texts within each topic, were randomized. Each text was displayed on a separate page, and the respective text-specific questions (interpretation of the text, confidence in interpretation) were displayed on the consecutive page, so that participants needed to answer from memory. This was done to ensure that the questions assessed actual interpretation, including potential distortions of the evidence, rather than a simple look-up of the information provided. Participants went through the survey at a self-paced speed.

Measures

Prior and posterior beliefs. The same items were used to assess prior and posterior beliefs. For climate change, participants indicated: “Do you think human activity is the cause of increasing temperatures?” on a 17-point scale ranging from from -8 (“I think that human activity is NOT the cause of increasing temperatures”) to 8 (“I think that human activity is the cause of increasing temperatures”). For nanotechnology, participants indicated: “Do you think that the positive outcomes of nanotechnology outweigh the risks?” on a 17-point scale ranging from from -8 (“I think that the risks of nanotechnology strongly outweigh the benefits”) to 8 (“I think that the positive outcomes of nanotechnology strongly outweigh the risks”), for the texts on nanotechnology.

Interpretation of the direction of evidence. Participants indicated their interpretation of the direction of evidence for climate change, and nanotechnology, each on a 17-point scale. Specifically, participants indicated their interpretation “This summary provides evidence that...” on a scale from -8 (“human activity is NOT the cause of increasing temperatures”), to 8 (“human activity is the cause of increasing temperatures”) for climate change, and from -8 (“nanotechnology risks outweigh benefits”) to 8 (“nanotechnology risks outweigh benefits”).

Metacognitive confidence in interpretation. Participants provided item-specific confidence judgment by indicating, after each interpretation of each text: “How certain are you that your assessment is correct?” on a 6-point scale ranging from 50% (“I guessed”) to 100% (“I am certain”).

Analysis

Task sensitivity. To measure the accuracy of the interpretation of the scientific evidence, we determined *task sensitivity d'* as specified in a Signal Detection Theory (SDT) framework by calculating the difference of the z-standardized False Positive, and the z-standardized True Positive rate. Task sensitivity d' reflects participants' ability to correctly distinguish between evidence as endorsing or rejecting anthropogenicity and risks, respectively. Ratings above 0 were classified as endorsement, ratings below zero were rated as rejection. Since accuracy was coded only with respect to rejection versus endorsement, ratings of 0 were always rated as an incorrect answer.

Metacognitive sensitivity. To measure metacognitive sensitivity, we determined *meta- d'* for each participant (Maniscalco & Lau, 2014). *Meta- d'* is a bias-free measurement of sensitivity in that it controls for metacognitive bias, participants' general tendency to report high/low values of confidence. *Meta- d'* expresses metacognitive sensitivity in an SDT framework, and assesses the degree to which participants' confidence judgments reflect accurate versus inaccurate object-level responses, controlling for their response bias. That is, in our case, metacognitive sensitivity reflects the degree to which participants differentiate between correct versus incorrect interpretation of the object-level evidence in their metacognitive judgment. To do so, *meta- d'* is defined as the object-level d' that would be *expected* to have produced the observed confidence data given the same response bias c , and given ideal metacognitive sensitivity. *Meta- d'* can be interpreted as the sensory evidence available for the metacognitive task in the same signal-to-noise ratio units that measures d' as the sensory evidence available for the object-level task. Hence, *meta- d'* values of zero indicate metacognitive performance at chance level, values < 0 indicate metacognitive performance below chance levels, and values > 0 indicate metacognitive

performance above chance level. To compute meta-d', we used a hierarchical Bayes procedure (Fleming, 2017), and code provided at <https://github.com/smfleming/HMeta-d>.

Influence of prior beliefs on interpretation of the evidence. To measure the influence of prior beliefs on the interpretation of the scientific evidence, linear regression models were employed following the analysis of Fryer, Jackson and Harms (2019). Interpretation ratings were averaged, separately per direction of evidence, and domain. The regression analysis was performed separately for each direction of evidence. The equations are of the form:

$$Interpretation_i = \alpha + \gamma * PriorBelief_i + \varepsilon_i. \quad (1)$$

with the index i denoting individuals, α and γ denoting are the regression parameters, and ε_i denoting the uncertainty for individual i .

This analysis provides the unique benefit of delivering regression parameters that can be readily interpreted by providing direct psychological meaning. First, the constant α corresponds to the *average interpretation* of the summary, such that the direction of the value of the parameter (positive or negative) indicates the interpreted direction of the evidence (endorsement or rejection). That is, positive values of α signify that a text was interpreted as endorsement on average, negative values of α signify that a text was interpreted as rejection.

More importantly, second, the regression parameter γ corresponds to the direction and strength of the influence of the prior belief on the interpretation of evidence. Positive values signify the extent to which an interpretation is influenced in the direction of the prior belief, that is, the extent to which the prior belief enhances the interpretation of the evidence in the direction of the prior. Negative values signify the extent to which an interpretation is influenced in the direction opposite the prior belief. Values of zero signify that the prior belief had no influence on the interpretation of a text. For example, consider a participant who has a strong prior belief that nanotechnology benefits outweigh its risks. In this case, positive values of γ signify that a text supporting this belief has a reinforcing influence on that belief, that is, further strengthens the belief in the direction of the prior.

The regression analysis was performed in R employing the linear model-function (lm) (R Core Team, 2018). Errors are calculated using the ordinary least square (OSL)-method (Seabold, and Perktold, 2010). To assess statistical significance of the difference of any two parameters

(e.g., comparing two groups of participants), we compared their respective 3- σ regions. Disjoint σ regions reflect the probability that those parameters are not equal.

Proportion of polarizers. To estimate the proportion of polarizers, we identified individuals who became more extreme in their prior compared to their posterior beliefs:

$$|Post_i| > |Prior_i|, \forall i \text{ with } |Prior_i| \neq 0. \quad (4)$$

Calculating the rate of occurrence of such individuals over all participants gives the *proportion of polarizers* G_{pol} :

$$G_{pol} = \frac{\sum \{i \in I \mid |Post_i| > |Prior_i|\}}{\sum \{i \in I\}} \quad (5)$$

The error was estimated as the relative Gaussian standard error $\frac{\Delta G_{pol}}{G_{pol}} = \frac{1}{\sqrt{n}}$ with n number of participants.

Do differences in task sensitivity, and metacognitive sensitivity moderate the relationship of prior beliefs and evidence interpretation? To analyze whether differences regarding task sensitivity (d'), and metacognitive sensitivity (meta- d') moderate the relationship between prior beliefs and the interpretation of the evidence, participants were split into high and low scorers for each variable. Splitting participants into categories provides the unique advantage that the slope γ remains a psychologically interpretable variable, namely the influence of prior beliefs on the interpretation of the evidence. As a consequence, high- and low-scorer of task sensitivity, and metacognitive sensitivity can be directly compared on the same scale to assess whether they differ in the extent to which the prior influences the interpretation of the evidence. Individuals were categorized based on their individual value relative to the mean for each variable such that individuals with values higher than the mean were categorized as high-scorer, and individuals with values lower than the mean as low-scorer.

The influence on the variables P on the prior-interpretation is calculated as follows:

$$Interpretation_{i \in P} = \alpha_P + \gamma_P * PriorBelief_{i \in P} + \varepsilon_{i \in P}, \quad (2)$$

where P denotes the subgroups for d' , and meta- d' .

Results

Tables 1 and 2 depict the means and standard deviations of the main measures employed in this study, prior and posterior beliefs, task sensitivity (d'), and metacognitive sensitivity (meta- d') for nanotechnology and climate change, respectively. For a comparison of meta- d' , and d' with respect to the statistical significance ($3\text{-}\sigma$ -region) of respective α and γ values, see Tables 4 (nanotechnology) and 5 (climate change).

Table 1. Means, standard deviations, and correlations with confidence intervals for nanotechnology.

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. Prior belief	2.59	3.37				
2. Posterior belief	1.83	3.33	.51** [.43, .58]			
3. Meta- d'	1.46	1.11	.15** [.05, .25]	.16** [.06, .26]		
5. d'	1.64	0.94	.06 [-.05, .16]	.01 [-.10, .11]	.42** [.33, .50]	.07 [-.03, .17]

Note. *M* and *SD* are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.

Table 2. Means, standard deviations, and correlations with confidence intervals for climate change.

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. Prior belief	4.36	4.33				
2. Posterior belief	3.26	4.59	.83** [.79, .86]			
3. Meta-d'	1.08	0.78	.19** [.09, .29]	.23** [.13, .33]		
5. d'	1.52	0.78	.04 [-.06, .15]	.04 [-.06, .14]	.41** [.32, .49]	.19** [.09, .29]

Note. *M* and *SD* are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.

Figure 1: Distribution of prior and posterior beliefs. The figure displays the distribution of prior (orange) and posterior (purple) beliefs for nanotechnology (panel A) and climate change (panel B) and the direction and strength of belief updating for nanotechnology (panel C) and climate change (panel D). For climate change, more positive values indicate stronger beliefs in the anthropogenicity of climate change. For nanotechnology, more positive values indicate stronger beliefs in the benefits of nanotechnology. Panel C and D display the number of participants arranged according to their difference between their prior and posterior belief. Polarizers, whose posterior beliefs shifted in the direction of their prior beliefs can be found in the bottom third of the graph.

Distribution of prior and posterior beliefs. Figure 1 shows the overall distribution of prior and posterior beliefs (panel A and B), as well as the individual-specific shifts of prior and posterior beliefs (panel C and D). For nanotechnology, the modal prior belief, endorsed by 34% of participants, was a neutral view concerning its benefits or risks, and the majority (56%) of participants reported an overall positive view on nanotechnology where the benefits outweigh the risks. For climate change, in contrast, the modal prior belief, endorsed by 29% of participants, was the strongest acceptance of anthropogenicity, and 81% of participants showed overall agreement with that statement. That is, participants held stronger prior beliefs for climate change compared to nanotechnology.

Figure 1, panel C and D shows that with respect to their specific belief-updating profiles, participants could be classified in five sub-groups: (i) those whose beliefs became more *moderate* (displayed in the upper third of the graph); (ii) those who did not update their beliefs, and (iii) those who flipped, that is whose posterior beliefs are of equal strength, but opposite direction compared to their prior beliefs (middle part of the graph); (iv) those who started from a neutral position and only developed a directed belief through the presented evidence (lower third of the graph); and (v) those whose posterior beliefs became more extreme in the direction of the prior belief, *polarizers* (lower third of the graph). The figure reveals that the belief-updating distributions were fundamentally different for the two domains. Panel C (nanotechnology) displays a tree-like structure, suggesting that the majority of participants reported initially neutral views, and only formed beliefs by being confronted with the evidence. Panel D (climate change), in contrast, displays a crescent-like structure suggesting that the majority of participants reported initially strong beliefs, and only few participants changed their views when being confronted with the evidence.

Polarization fingerprints of both domains. The total proportion of polarizes, participants who shifted towards more extreme values in the direction of their prior beliefs after reading the scientific evidence, $8.76\% \pm 0.46\%$ for nanotechnology, and $11.9\% \pm 0.63\%$ for climate change. That is, nanotechnology was a more heavily polarizing topic compared to climate change in the present sample as well.

Figure 2: Sub-groups of participants based on their specific belief-updating profiles. The figure displays the five different sub-groups of participants, that is (i) those whose beliefs became more moderate (depolarizers, red); (ii) those who did not update their beliefs (no-change, green), and (iii) those who flipped, that is whose posterior beliefs are of equal strength, but opposite direction compared to their prior beliefs (flip, khaki); (iv) those who started from a neutral position and only developed a directed belief through the presented evidence (opinion creation, blue); and (v) those whose posterior beliefs became more extreme in the direction of the prior belief (polarizers, magenta).

Distinct polarization “fingerprints” emerged for the two topics. For nanotechnology (Figure 2, panel A), almost all polarizers (pink) were found in one group, namely the upper right corner, suggesting that most participants who polarized were those who held strong, initial beliefs in the benefits of nanotechnology. For climate change, in contrast, polarizers fell into two groups: those in the upper right corner, starting with strong prior beliefs in the anthropogenicity of climate change, and those in the lower left corner, starting with strong beliefs that climate change is not anthropogenic (Figure 2, panel B).

Taken together, the present results suggest that nanotechnology was a more polarized topic compared to climate change, as found in previous research (Drummond & Fischhoff, 2017).

Figure 3: Relationship between prior beliefs and the average interpretation of the evidence. The figure displays the average interpretation for each participant for nanotechnology (panel A) and climate change (panel B), separate per direction of evidence. Regression lines are displayed with 95% confidence interval. The marginal histograms show the distribution of prior beliefs (top) and of the average rating of the summaries (right).

Relationship between prior beliefs and interpretation of the evidence. Figure 3 depicts the relationship between participants' prior beliefs and the average rating of the direction of the evidence for nanotechnology (panel A) and climate change (panel B). The Figure demonstrates, first, that participants were able to correctly classify the direction of the evidence in that endorsing evidence was rated as endorsing on average, and rejecting evidence was rated as rejecting on average. More importantly, second, the direction and strength of the influence of the prior beliefs γ on the interpretation of the evidence was positive, for both directions of evidence, and for both climate change and nanotechnology (see Table 3 for the specific values of α and γ). This result suggests that participants' interpretations were influenced in the direction of their prior beliefs. Specifically, prior beliefs moved the interpretation of the evidence between 11% and 26% of the strength of the prior in the direction of the prior. These results align with the

results on the direction and strength of evidence distortion in the direction of prior beliefs found in previous research (Fryer, Jackson, & Harms, 2019).

Table 3. Relationship between prior beliefs and interpretation of the scientific evidence for nanotechnology and climate change.

Nanotechnology	α	$\Delta\alpha$	γ	$\Delta\gamma$
Endorsing	3.916	0.096	0.260	0.023
Rejecting	-3.715	0.117	0.135	0.028
Climate change				
Endorsing	5.073	0.124	0.238	0.020
Rejecting	-5.044	0.145	0.145	0.024

Do task sensitivity and metacognitive sensitivity relate to polarization? We compared whether task sensitivity (d'), and metacognitive sensitivity (meta- d') relate to polarization over the science (see Tables 4 and 5 for parameter values). Higher task sensitivity, first, was related to a lower proportion of polarizes, for both nanotechnology and climate change, suggesting that participants who were more accurate in interpreting the evidence were less likely to polarize in their beliefs. Most importantly, second, for climate change, but not for nanotechnology, the proportion of polarizers was higher among participants with lower, compared to higher metacognitive sensitivity (Figure 4). These results suggest that higher metacognitive sensitivity was related to lower polarization for the heavily politicized topic of climate change but not to the lesser politicized topic of nanotechnology. Since metacognitive sensitivity as measured with meta- d' controls for metacognitive bias, these results hold independently of participants' general tendency to report high/low values of confidence.

Figure 4: Proportion of polarizers for nanotechnology (A) and climate change (B). The figure displays the proportion of polarizers for low- and high-meta-d' scorer.

Table 4. Relationship between metacognitive sensitivity (meta-d'), and task sensitivity (d') and parameters (i) α (mean interpretation of evidence), (ii) γ (relationship between prior beliefs and interpretation of evidence), and (iii) the proportion of polarizes for nanotechnology.

NT	meta-d'					
	Low-scorer (n = 201)			High-scorer (n = 153)		
	$\alpha \pm \Delta\alpha$	$\gamma \pm \Delta\gamma$	Pol $\pm\Delta$ Pol(%)	$\alpha \pm \Delta\alpha$	$\gamma \pm \Delta\gamma$	Pol $\pm\Delta$ Pol(%)
End.	2.988 $\pm$ 0.132*	0.338 $\pm$ 0.034*	9.45 $\pm$ 0.67	5.410 $\pm$ 0.113*	0.097 $\pm$ 0.024*	7.84 $\pm$ 0.63
Rej.	-3.152 $\pm$ 0.148*	0.227 $\pm$ 0.038		-4.629 $\pm$ 0.175*	0.110 $\pm$ 0.037	

	d'					
	Low-scorer (n = 126)			High-scorer (n = 228)		
	$\alpha \pm \Delta\alpha$	$\gamma \pm \Delta\gamma$	Pol $\pm\Delta$ Pol(%)	$\alpha \pm \Delta\alpha$	$\gamma \pm \Delta\gamma$	Pol $\pm\Delta$ Pol(%)
End.	2.185 $\pm$ 0.192*	0.514 $\pm$ 0.045*	14.3 $\pm$ 1.27*	4.892 $\pm$ 0.090*	0.112 $\pm$ 0.021*	5.70 $\pm$ 0.38*
Rej.	-2.113 $\pm$ 0.210*	0.304 $\pm$ 0.049*		-4.587 $\pm$ 0.113*	0.036 $\pm$ 0.027*	

Note. Significant differences between high- and low-scorer (3- σ -region) are denoted with *.

Table 5. Relationship between metacognitive sensitivity (meta-d'), and task sensitivity (d') and parameters (i) α (mean interpretation of evidence), (ii) γ (relationship between prior beliefs and interpretation of evidence), and (iii) the proportion of polarizes for climate change.

CC	meta-d'					
	Low-scorer (n = 193)			High-scorer (n = 161)		
	$\alpha \pm \Delta\alpha$	$\gamma \pm \Delta\gamma$	Pol $\pm\Delta$ Pol(%)	$\alpha \pm \Delta\alpha$	$\gamma \pm \Delta\gamma$	Pol $\pm\Delta$ Pol(%)
End.	4.063 $\pm$ 0.174*	0.306 $\pm$ 0.03*	18.1 $\pm$ 1.30*	6.778 $\pm$ 0.116*	0.079 $\pm$ 0.018*	4.35 $\pm$ 0.34*
Rej.	-4.402 $\pm$ 0.269*	0.209 $\pm$ 0.045*		-6.032 $\pm$ 0.234*	0.057 $\pm$ 0.036*	

	d'					
	Low-scorer (n = 93)			High-scorer (n = 261)		
	$\alpha \pm \Delta\alpha$	$\gamma \pm \Delta\gamma$	Pol $\pm\Delta$ Pol(%)	$\alpha \pm \Delta\alpha$	$\gamma \pm \Delta\gamma$	Pol $\pm\Delta$ Pol(%)
End.	2.218 $\pm$ 0.298*	0.535 $\pm$ 0.049*	19.4 $\pm$ 2.01*	6.114 $\pm$ 0.096*	0.129 $\pm$ 0.016*	9.19 $\pm$ 0.57*
Rej.	-2.156 $\pm$ 0.440*	0.330 $\pm$ 0.072*		-6.096 $\pm$ 0.114*	0.036 $\pm$ 0.019*	

Note. Significant differences between high- and low-scorer (3- σ -region) are denoted with *.

Figure 5: Moderating influence of metacognitive sensitivity (meta-d') on the relationship between prior beliefs and interpretations of the scientific evidence for nanotechnology. The figure displays the relationship between prior beliefs and interpretations of the scientific evidence, separately for participants high, compared to participants low in metacognitive sensitivity (meta-d'), and separately per direction of the evidence (endorsing, Panel A versus rejecting, Panel B). Regression lines are displayed with 95% confidence interval. The marginal histograms show the distribution of prior beliefs (top) and the average interpretation of the summaries (right).

For both topics meta-d' high-scorer, and d' high-scorer rated the summaries on average higher than low-scorer. That is, participants with low metacognitive sensitivity rated the summaries as less strong evidence than participants with high metacognitive sensitivity while at the same time the influence of their prior beliefs were stronger compared to participants with high metacognitive sensitivity. Put differently, evidence disproving prior beliefs of participants with low metacognitive sensitivity would be rated as almost neutral or even as confirming evidence given a strong prior belief.

Figure 6: Moderating influence of metacognitive sensitivity (meta-d') on the relationship between prior beliefs and interpretations of the scientific evidence for climate change. The figure displays the relationship between prior beliefs and interpretations of the scientific evidence, separately for participants high, compared to participants low in metacognitive sensitivity (meta-d'), and separately per direction of the evidence (endorsing, Panel A versus rejecting, Panel B). Regression lines are displayed with 95% confidence interval. The marginal histograms show the distribution of prior beliefs (top) and the average interpretation of the summaries (right).

Does metacognitive sensitivity (meta-d') moderate the relationship between prior beliefs and evidence interpretation? To explore the anticipated cognitive process behind the effect that metacognitive sensitivity relates to polarization, we investigated whether metacognitive sensitivity (meta-d') moderates the relationship between participants' prior beliefs and their interpretation of the scientific evidence. If our conjecture that higher metacognitive sensitivity attenuates the influence of the prior on the interpretation of the evidence, this relationship should be weaker for participants with higher, compared to lower values of meta-d'.

Figure 6 suggest that for climate change, the influence of the prior on the interpretation of the evidence was weaker for participants with higher, compared to lower values of meta-d', for

both directions of evidence: For participants with low metacognitive sensitivity, there was a moderate relationship for the positive direction of evidence (endorsing): $r_{CC_Endorsement}(191)=.40$, $95\%CI=[.27, .51]$ and a low relationship for the negative direction of evidence (rejecting): $r_{CC_Rejection}(191)=-.21$, $95\%CI=[-.34, -.07]$). For participants high in metacognitive sensitivity, the relationship between prior beliefs and the interpretation of the evidence was low for the positive direction of evidence (endorsing): $r_{CC_Endorsement}(159)=.22$, $95\%CI=[.06, .36]$ and for the negative direction of evidence (rejection) it was virtually non-existent: $r_{CC_Rejection}(159)=-.09$, $95\%CI=[-.25, -.06]$.

Figures 5 suggest that, for nanotechnology higher meta-d' attenuated the relationship between prior beliefs and the interpretation of the evidence only for evidence endorsing nanotechnology benefits: For participants with low metacognitive sensitivity, there was a moderate relationship for the positive direction of evidence (endorsing): $r_{NT_Endorsement}(199)=.40$, $95\%CI=[.28, .51]$, and a low relationship for the negative direction of evidence (rejecting): $r_{NT_Rejection}(199)=-.27$, $95\%CI=[-.39, -.14]$. For participants high in metacognitive sensitivity, the relationship between prior beliefs and the interpretation of the evidence was low for the positive direction of evidence (endorsing): $r_{NT_Endorsement}(151)=.14$, $95\%CI=[-.02, .29]$. However, for the negative direction of evidence (rejecting) the strength of the relationship was similar to that of participants with low metacognitive sensitivity: $r_{NT_Rejection}(151)=-.23$, $95\%CI=[-.38, -.07]$.

That is, for climate change, metacognitive sensitivity moderated the relationship between prior beliefs and evidence interpretation, and this held irrespective of the direction of the evidence. For nanotechnology, in contrast, metacognitive sensitivity moderated the influence of the prior only for endorsement of nanotechnology benefits, that is, where participants held initially strong beliefs.

Discussion

Civil polarization has long been the domain of political and religious worldviews. Recent years, however, have seen a marked increase in the polarization over seemingly emotionless science such as climate change, vaccination, COVID-19, or nanotechnology. To explain polarization over science, political, sociological, and psychological research has identified societal macro-phenomena as well as cognitive micro-factors that influence how citizens reason

about the science (Hornsey et al., 2016), numeracy (Kahan et al., 2017), or scientific literacy (Kahan, 2012). Here we take a radically different perspective, and highlight the effects of metacognition, how citizens reason *about their own reasoning*. Leveraging methods from Signal Detection Theory, we found that higher metacognitive sensitivity (measured as *meta-d'*), an increased insight into the validity and fallibility of own interpretations of the available evidence, reduced polarization over the heavily contested topic of climate change, but not the less heavily contested topic of nanotechnology. Specifically, among citizens with lower metacognitive sensitivity, the proportion of polarizers over climate change was 4 times higher than among citizens with higher metacognitive sensitivity.

Furthermore, the present research also isolated a cognitive mechanism that explains *why* individual-level insight can relate to group-level polarization over contested science. Prior research has established a link between the degree of politicization of different scientific domains, and the accuracy of metacognitive insight in that domain (Fischer et al., 2019). Furthermore, emerging evidence suggests a relationship between metacognitive insight, and the accuracy of evidence accumulation, and belief updating (Fischer & Said, preprint; Sinclair et al., 2020). It has also been found that metacognitive insight in domain-general tasks relates to political attitudes (Rollwage et al., 2018; Zmigrod et al., 2019). Based on this evidence, we expected that metacognitive insight into the accuracy of one's interpretation of scientific evidence might relate to belief-updating about politicized science. And indeed, results suggest that lower insight into the accuracy of own interpretations of the available evidence fostered updating in the direction of strong prior beliefs (at the expense of the evidence); conversely, higher metacognitive insight fostered belief-updating in the direction of the evidence (at the expense of prior beliefs).

The present research found an influence of metacognition for the heavily politicized topic of climate change, but not for the the less heavily politicized topic of nanotechnology. Specifically, (i) the prior belief distributions of both topics were markedly different in that more participants started out with neutral views on nanotechnology compared to climate change; and (ii) the polarization fingerprints of both topics differed in that for nanotechnology, participants who polarized were found almost exclusively among endorsers of nanotechnology benefits (but

not risks), whereas for climate change, participants polarized on both ends of the spectrum (endorsing and rejecting anthropogenicity). Results furthermore revealed that metacognitive sensitivity moderated the relationship between prior beliefs and interpretation of the evidence on both ends of the belief spectrum for climate change. In contrast, metacognitive sensitivity moderated this relationship only for endorsers of nanotechnology benefits, that is, only where participants held initially strong beliefs.

Taken together, these results highlight a novel mechanism that, among others, explains group-level polarization over contested science: individual-level insight into the accuracy of interpretations of the available evidence. This may be particularly relevant in areas of politicized science where external information on the accuracy of information is noisy in that false and misleading information exists alongside information that is scientifically accurate. In noisy decision environments lacking unequivocal external feedback about the reliability of information, citizens might be particularly prone to relying on internal cues to accuracy such as metacognitive confidence (Desender et al., 2018; Rahnev et al., 2015). In line with a mechanism whereby the degree of politicization, and hence noisiness, of the decision environment influences the degree of reliance on internal, metacognitive cues for belief-updating, the present results found a moderating influence of metacognitive insight for climate change, but not nanotechnology. Metacognitive insight hence appears to be more pronounced for science that is more, compared to less, contested.

Human interpretations of evidence about the external world are imperfect: We tend to mis-interpret evidence asymmetrically as a function of prior beliefs (Corner et al., 2012; Fryer Jr et al., 2019), worldviews (Kahan et al., 2017), or partisanship (for a meta-analysis, Ditto et al., 2019). Metacognitive sensitivity, however, enable us to do justice to this fundamental inclination by evaluating varying levels of accuracy of interpretation with matching levels of confidence. This process of stepping back from own interpretations has been described as an “internal tribunal” that rules on the soundness of own interpretations (Fleming, 2014). In the present case, participants with more accurate “internal tribunals” were less likely to be lead astray by their own prior beliefs, the lens through which humans generally tend to view the scientific evidence. As a consequence, they were less likely to drive belief polarization.

The present metacognitive view offers an interesting leverage point to address societal polarization over contested science. Specifically, interventions targeted at increasing metacognitive accuracy (Elosúa et al., 2013; Zohar & Barzilai, 2013) may provide an effective means to mitigate societal polarization over science. This is encouraging since reducing political polarization is particularly relevant for domains where unified, collective action is required, such as for combating climate change (Brechin, 2016; Harris, 2007), but where prior research has repeatedly demonstrated that simply increasing the accuracy of object-level cognition such as scientific literacy, or numeracy has limited success in reducing societal polarization, and may in fact even propel societal divide (Kahan, 2012, 2017).

To conclude, the present demonstrate the importance for individual-level insight into interpretations of scientific evidence for group-level polarization over contested science, that is, science where citizens hold strong prior beliefs. Undifferentiated faith in own interpretations of scientific evidence drives polarization over contested science, while more nuanced insight into the limitations and fallibility of own interpretations reduces polarization over contested science. By demonstrating the impact of metacognition, the present results increase our understanding of the mechanisms that may link individual-level cognition and group-level polarization over contested science.

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Author Contribution

Study Design: NS. Study Implementation: GA, NS. Data Analysis: GA, NS. Data Visualization: NS, HF. Writing: HF. All authors edited and approved the manuscript.

Data Availability

The data and the analysis code for all results and figures of this study will be made available after publication.