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Importance of domain-specific metacognition for explaining beliefs about politicized science: The case of climate change

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Abstract

One of the oldest debates in psychological research into politicized science such as nanotechnology, vaccination, or climate change centers around the role of knowledge. Does increased knowledge of the science affect beliefs about it? While research has traditionally focused on the role of object-level knowledge, here we highlight the importance of meta-knowledge: How much people believe they know about the science. Specifically, we demonstrate the importance of meta-knowledge (measured as confidence in knowledge) for explaining beliefs about science with one of the most contested examples: climate change. For a national Germany sample ($N = 509$), frequentist and Bayesian analyses demonstrated that climate change meta-knowledge was predictive of climate change beliefs, above and beyond object-level climate change knowledge. These results held for both the belief that climate change is risky, and the belief that climate change is anthropogenic, and when controlling for political attitude, and demographic variables. Furthermore, for a second national German sample ($N = 588$), confidence in climate change knowledge was a stronger predictor of climate change beliefs compared to confidence in other-domain (biological and physical) science knowledge, suggesting that outside of the respective domain, metacognitive confidence did not explain beliefs. These results highlight the relevance of domain-specific metacognition for explaining beliefs about the contested science of climate change. By demonstrating the relevance of metacognitive, rather than solely object-level thought, these results add to our understanding of the cognitive mechanisms involved in the formation of beliefs about politicized science.

Keywords: Politicized science, Climate change, Metacognition, Insight

One of the oldest and most fundamental questions on the determinants of beliefs about politicized science such as nanotechnology, vaccination, or climate change, centers around the role of knowledge: Does increased knowledge of the science affect beliefs about it? While considerable research exists on the explanatory role of object-level cognition (Hornsey, Harris, Bain, & Fielding, 2016; Shi, Visschers, Siegrist, & Arvai, 2016), here we highlight the importance of metacognition. Specifically, we demonstrate the role of meta-knowledge (or confidence in knowledge; Fleming & Lau, 2014) for explaining beliefs about science with one of the most contested examples: climate change (Drummond & Fischhoff, 2017). In the area of climate change, citizens are confronted with a mix of accurate information, and misinformation (Del Vicario et al., 2016; Vosoughi et al., 2018) that constantly challenges the credibility of citizens' existing knowledge. In such a noisy and potentially confusing information environment, meta-knowledge could serve as a critical guide when forming beliefs supported by knowledge, particularly when unequivocal external feedback about the accuracy of knowledge is absent.

It is virtually unknown, however, whether meta-knowledge and metacognitive sensitivity (knowing what you know, and what you don't) relate to climate change beliefs. This is highly surprising given strong theoretical reasons to suspect such a relationship. First, with respect to meta-knowledge, it was found that confidence in knowledge
may modulate how knowledge is translated into congruent judgment , even when controlling for the accuracy of knowledge (Allgood & Walstad, 2016; Hadar, Sood, & Fox, 2013). Hence, higher confidence in climate change knowledge may increase the likelihood of this knowledge being translated into congruent belief. And second, with respect to sensitivity, (i) to form beliefs supported by knowledge, as well as (ii) to update knowledge in light of novel information, citizens need insight

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into which pieces of their currently held knowledge are incorrect and should not be trusted, and which ones are correct and should be trusted. Hence, domain-specific metacognitive sensitivity may explain climate change beliefs, above and beyond the accuracy of object-level climate change knowledge.

Here we investigate whether, and in how far domain-specific meta-cognition explains climate change beliefs, above and beyond object-level knowledge in a nationally balanced quota sample of German citizens. For clarity, we use the term *subjective knowledge* to refer to previously used one-item measurement of participants' subjective assessment of their knowledge (e.g., "How informed do you consider yourself to be on he issue of global warming?"; Stoutenborough & Vedlitz, 2014), which precludes estimating different facets of metacognition; we use the term *domain-specific metacognition*, when participants indicate, after each objective knowledge item, how confident they are that they answered correctly. While both one-item, global assessments of subjective knowledge, as well as item-specific assessment of confidence determine how much people believe they know about the issue under consideration, only item-specific confidence allows estimating different facets of metacognition.

1. Objective and subjective climate change knowledge and beliefs

In line with previous research, we define beliefs as statements about the truth value of a given proposition (Wolfe & Williams, 2018). Beliefs are distinct from knowledge in that people can have knowledge of claims (such as that science claims that climate change is mainly caused by fossil fuel emissions) without believing them to be true. We define knowledge operationally as accurate answers to declarative statements, with accuracy–in the present case of climate change–, defined in terms of correspondence to scientific consensus as described in the IPCC reports.

To test the relationship between climate change knowledge and beliefs, studies using subjective knowledge as a measure of objective knowledge yielded results that vary in accordance to political attitude. The feeling to know more about global warming was positively associated with concern for Democrats, but unrelated for Republicans (Malka, Krosnick, & Langer, 2009). Furthermore, within 10 nationally representative US polls between 2001 and 2010, self-reported understanding was positively associated with concern over climate change for liberals and Democrats, and more weakly so or even negatively so for conservatives and Republicans (McCright & Dunlap, 2011b). Drawing on the same data, denial of climate change was highest among white male conservatives who claim to understand climate change very well (McCright & Dunlap, 2011a).

As opposed to subjective measures, objective measures of climate change knowledge tend to show a consistently positive (albeit small) predictive value of climate change knowledge for climate change beliefs. A large study among citizens from Switzerland found that those who know more about climate change tended to be more concerned (Tobler, Visschers, & Siegrist, 2012), understanding of the causes of global warming was the single best predictor of behavioral intentions to act on global warming among 1218 Americans (Bord, O'Connor, & Fisher, 2000), knowledge about the causes of climate change predicted concern about climate change in six politically and culturally diverse countries (Shi et al., 2016), and in 119 countries, understanding the anthropogenicity of climate change even proved the strongest predictor of climate change risk perceptions (Lee, Markowitz, Howe, Ko & Leiserowitz, 2015).

In terms of the size of the variance explained by knowledge, estimates range between 2% to 18% for different countries (Shi et al., 2016), and an average estimate of 6.3% was revealed by a meta-analysis (Hornsey et al., 2016).

2. Metacognition and beliefs about politicized issues

There is emerging evidence that domain-general metacognitive ability as measured in low-level perceptual tasks can explain beliefs about politicized issues. Cognitive mechanisms behind this effect appear to be that metacognitive confidence guides information search in uncertain environments (Schulz et al., 2020), and that metacognitive sensitivity is required to integrate evidence, including disconfirmatory evidence (Rollwage, Dolan, & Fleming, 2018). Indeed, it was found that a lower tendency to seek out additional, potentially correcting, information after an initial decision was lower for more dogmatic participants, especially when that decision was made with low confidence (Schulz et al., 2020). Furthermore, the degree of belief updating after receiving corrective feedback about prediction errors related to trivia statements was found to be negatively related to right-wing authoritarianism (Sinclair, Stanley, & Seli, 2020), and slower evidence accumulation in a perceptual decision-making task was found to be related to dogmatism (Zmigrod, 2020). It has also been found that cognitive flexibility measured with the Wisonsin Task and the Remote Associates Test predicted political beliefs, such as about Brexit (Zmigrod, Rentfrow, & Robbins, 2018), or endorsement of violence to protect the national ingroup (Zmigrod, Rentfrow, & Robbins, 2019).

While these results underscore the relevance of domain-general metacognitive ability for explaining citizens' political beliefs and attitudes, considerably less is known about whether and how domain-specific meta-knowledge is related to beliefs about politicized science.

3. The present study

The current research extends existing research in three important aspects. First, previous research found that subjective measures of climate change knowledge tend to explain less variance in climate change beliefs compared to objective measures (for a meta-analysis, see Hornsey et al., 2016). This finding has typically been explained by noting that subjective measures lack reliability compared to objective measures (e.g., Roser-Renouf & Nisbet, 2008). Here we argue, however, that when understood as a measure of objective knowledge, subjective measures of knowledge do represent an unreliable proxy. But subjective beliefs about the degree of one's knowledge capture additional, and different information that is not represented in measures of objective knowledge, namely domain-specific metacognition. Moreover, the typical result of lower predictivity of subjective compared to objective knowledge may be a methodological artifact since subjective knowledge was typically assessed using one-item measures, whereas objective knowledge was measured using whole scales. Using single-item measures, the reliability of the confidence scale is unknown (and unknowable). The lower predictivity could hence be the result of subjective knowledge not only being a less reliable measure of objective knowledge, but also an unreliable measure of subjective knowledge itself. Here we use a repeated assessment of confidence in knowledge that allows estimating the reliability of the confidence scale.

Second, as subjective knowledge was typically understood as a proxy of objective knowledge, previous studies did not investigate the predictive value of subjective knowledge, controlling for objective knowledge. One notable exception is a study that found that subjective knowledge was a negative, and objective knowledge a positive predictor of climate change concern (Stoutenborough & Vedlitz, 2014). However, this study also used a global assessment of subjective knowledge ("How informed do you consider yourself to be on the issue of global warming?") that cannot be directly mapped on the objective knowledge scale, and hence does not allow for estimating sensitivity. Here we use a repeated measurement of confidence that allows determining how different facets of metacognition relate to beliefs, above and beyond knowledge.

And third, climate change knowledge items typically have the form of true/false statements such as "Burning oil produces CO_2" (Shi et al.,

2016), and accuracy is determined with reference to scientific consensus, that is, relative to external reality. However, citizens might answer knowledge questions not in accordance to what science believes, but what they personally believe, that is, relative to internal reality. For example, citizens might well know that science says that burning oil produces CO_2, but still answer FALSE, simply because they themselves do not hold the statement to be true. Such response patterns can (i) bias the relationship between knowledge and beliefs; and (ii) confound assessment of knowledge with assessment of beliefs. Here we introduce each climate change knowledge statement with: "Science says that…", thereby explicitly specifying that participants should answer in accordance to science's belief about climate change.

The goal of the study is to investigate whether domain-specific metacognition predicts climate change beliefs (a) not at all, (b) in addition to knowledge, (c) in interaction with knowledge, or (d) at the expense of knowledge.

4. Study 1

4.1. Methods

All data for study 1 and study 2 are freely accessible under osf.io/dwbt2 (Fischer, 2020, dataset). The analysis code (in R) to produce all results, Figures and Tables is available under https://osf.io/7rnt4/. For both study 1 and study 2, we analyzed data that have been collected as part of a different project (Fischer, Amelung, & Said, 2019).

4.2. Participants

A total of $N = 509$ German citizens were recruited through the polling company YouGov. The sample constitutes a nationally balanced quota sample with respect to gender (female: $n = 267$, 53%), age (mean = 48.5, range = 18–88), and geographical distribution. Participants had a range of educational backgrounds (lowest school leaving certificate: 14%; middle school leaving certificate: 39%;highest school leaving certificate: 20%; Bachelor: 7%; Master: 13%, PhD: 1%; other: 4%; nine participants did not indicate their education), and a wide range of professions.

4.3. Procedure

The survey was conducted in the following order: Political view, climate change beliefs, knowledge and meta-knowledge, demographics.

4.4. Measures

4.4.1. Climate change knowledge

Participants judged a total of eight statements about climate change (four TRUE, four FALSE) taken from previous research (Sundblad, Biel, & Gärling, 2009). Each statement started with "Science says that...". Participants answered "yes, science says that", or "no, science does not say that". In contrast to previous research (Tobler et al., 2012), an "I don't-know"-option was not given. This was done (i) to assess meta- knowledge using a full-range scale as opposed to a binary statement, (ii) to assess any partial knowledge participants may have, and (iii) because people are diferentially adverse to guessing an answer, leading to biased knowledge scores due to skipped items (Baldiga, 2013).

The knowledge statements covered the areas of causes, state, and consequences of climate change, and were: The global average temperature in the air has increased approx. 3.1°C in the past 100 years. (False); The 1990s was the warmest decade during the past 100 years. (False); The global change in temperature in the past 100 years is the largest during the past 1000 years. (True); Climate change is mainly caused by a natural variation in sunbeam and volcanic eruption. (False); Carbon dioxide concentration in the atmosphere has increased more than 30% during the past 250 years. (True); The increase of greenhouse gases is mainly caused by human activities. (True); The blanket of snow in the Northern Hemisphere has decreased approximately 10% since the 1960s. (True); An increasing amount of greenhouse gases increases the risk of more UV-radiation and therefore a larger risk of skin cancer. (False).

4.4.2. Meta-knowledge (confidence)

Participants indicated, after each knowledge item: "How certain are you that your answer is correct?" on a 6-point scale ranging from 50% to 100%, where all ticks were labeled with %-values, and the scale end points additionally had verbal descriptions ("50%: not at all certain, I was guessing"; "100%: certain, I know the answer"). Confidence was coded on a scale from 0.5 to 1.0. Reliability of the confidence scale was high, $\text{alpha}_{\text{study1}} = 0.86$, $95\%CI = [0.84, 0.88]$; $\text{alpha}_{\text{study2}} = 0.87$, $95\%CI = [0.85, 0.89]$.

4.4.3. Political orientation

Participants indicated "When talking about politics, one often hears the concepts 'left' and 'right'. We would like to know from you where you would place yourself" on a 9-point scale (1: left; 9: right).

4.4.4. Climate change beliefs

Participants indicated: "How much do you agree with the following statements: 1. "Climate change is mostly caused by humans" and. 2. "Climate change is risky", each on a 5-point scale ("1: I don't agree at all"; 5: "I totally agree"). Correlation between belief items was high, $r_{\text{study1}}(507) = 0.64$, $95\%CI = [0.59, 0.69]$; $r_{\text{study2}}(586) = 0.61$, $95\%CI = [0.56, 0.66]$.

4.5. Analysis

4.5.1. Knowledge

To measure the accuracy of knowledge, we used d' as specified in a Signal Detection Theory (SDT) framework, by quantifying the difference between the z-transformed True Positive, and the z-transformed False Positive rate in the knowledge test.

4.5.2. Meta-knowledge

To measure meta-knowledge, we used participants' *mean confidence* in their knowledge (Fleming & Lau, 2014). Since confidence also reflects participants' general tendency to report high or low confidence judgments, mean confidence is indicative of metacognitive bias.

4.5.3. Metacognitive sensitivity

As a bias-free measure of metacognitive sensitivity, we used *meta-d'* (Maniscalco & Lau, 2014). *Meta-d'* expresses metacognitive sensitivity in an SDT framework, and assesses the degree to which participants' confidence judgments reflect accurate versus inaccurate responses to the knowledge items, controlling for their response bias. 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.

4.6. Results and discussion

Descriptive results on the distribution of political attitude and climate change beliefs is given in Fig. 1. Means, standard deviations and correlations of all measures used in this study are given in Table 1.

4.6.1. Metacognition as a predictors of climate change beliefs: frequentist and Bayesian regression

We estimated in how far different aspects of climate change meta-cognition predict climate change beliefs above and beyond knowledge. We first ran four multiple ordinary least squares (OLS) regression models, separately for each climate change belief (risky, anthropogenic), with knowledge (d'), political attitude, and demographic variables (gender, age, education) as the baseline model, and subsequently entering meta-knowledge (confidence) and meta-cognitive sensitivity (meta-d') (Table 2, Table 3). Gender (1 = male; 2 = female) and education (1: lowest German school leaving exam; 1: German middle school leaving exam; 3: highest German school leaving exam; 4: Bachelor; 5: Master; 6: PhD; citizens indicating "other" or not indicating their education were excluded) were dummy-coded. Results showed that, for both climate change beliefs, meta-knowledge predicted climate change beliefs above and beyond the baseline model.

We additionally ran Bayesian regression analyses, again separately for both climate change beliefs. To calculate the Bayes factors, we used a default specification of priors (Wetzels et al., 2011), as implemented in the R package *BayesFactor*. Bayesian regression selects the best model from all possible combinations of predictors, where the best model is the one that balances parsimony and predictivity. The Bayesian analysis corroborated results from the frequentist analysis. Specifically, Bayesian regression revealed that, for both climate change beliefs, the best model was one that included knowledge (d') + political attitude + meta-knowledge (confidence). The Bayes Factors for this model were $BF_{10\_risky} = 112{,}639{,}478$ and $BF_{10\_anthropogenic} = 72{,}046$, respectively, indicating that the data were approx. 112 million, and 72.000 times more likely under this model compared to under the intercept-only model.

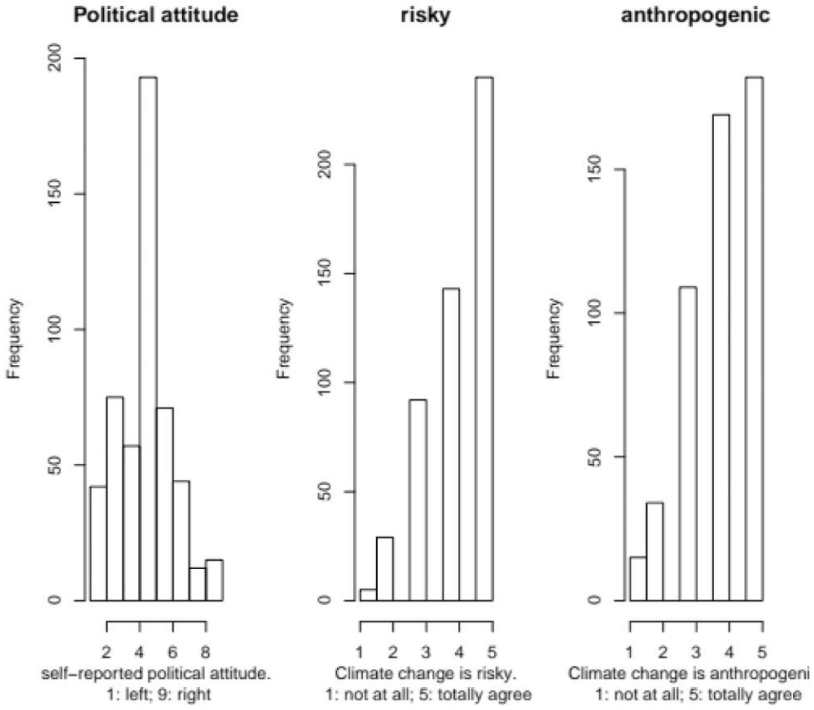

Fig. 1. Distributions of self-reported political attitude, beliefs that climate change is risky, and beliefs that climate change is anthropogenic.

We tested whether the influence of meta-knowledge changes as a function of the level of object-level knowledge. Differential influence of meta-knowledge could emerge if, for example, participants with low levels of knowledge were particularly prone to relying on their subjective confidence. However, this largely appeared not to be the case in that the relationship between metacognitive confidence and climate change beliefs was broadly similar across different levels of climate change knowledge, with only one meaningful exception (low levels of knowledge for beliefs about anthropogenicity; Fig. 2). In total, higher levels of confidence in knowledge tended to be related to increased climate change beliefs across different levels of knowledge.

4.6.2. Knowledge, meta-knowledge and political attitude

We first determined in how far climate change is a politicized subject among German citizens by correlating climate change beliefs with self- reported political attitude. As Fig. 3 shows, moderate negative relationships were revealed for both the belief that climate change is risky, r (507) = −0.23, 95% CI = [−0.31, −0.14], and the belief that climate change is anthropogenic, r (507) = −0.17, 95% CI = [−0.26, −0.09], indicating that participants who self-identify as on the right of the political spectrum tended to report lower belief that climate change is risky, and that it is anthropogenic.

We investigated whether the predictive value of knowledge changes across the political spectrum as indicated by previous research using one-shot measures of subjective knowledge (Malka et al., 2009; McCright & Dunlap, 2011a). As Fig. 4 shows, this largely appeared not to

Table 1
Means, standard deviations, and correlations of measures used in study 1.

Variable	*M*	*SD*	1	2	3	4
1. anthropogenic	3.92	1.05				
2. risky	4.15	0.97	0.64** [0.59, 0.69] BF = 5.0			
3. knowledge (d')	0.52 (range: −1.81-2.56)	0.70	0.21** [0.12, 0.29] BF = 5991.0	0.19** [0.10, 0.27] BF = 651.2		
4. meta-knowledge (confidence)	0.72	0.12	0.16** [0.08, 0.25] BF = 97.8	0.24** [0.16, 0.32] BF = 380,064.3	0.20** [0.11, 0.28] BF = 2478.3	
5. metacognitive sensitivity (meta-d')	0.21	0.57	0.14** [0.05, 0.22] BF = 11.5	0.14** [0.06, 0.23] BF = 16.5	0.24** [0.16, 0.32] BF = 529,869.8	0.39** [0.32, 0.46] BF = 1.59e+17

Note. M and *SD* are used to represent mean and standard deviation, respectively. Confidence scale represents values from 0.5 (50% confidence) to 1.0 (100% confidence). Values in square brackets indicate the 95% confidence interval for each correlation. * indicates $p < .05$. ** indicates $p < .01$. BF: Bayes Factor.

Table 2
Multiple regression analyses predicting belief that climate change is anthropogenic from climate change knowledge, meta-knowledge (confidence), and metacognitive sensitivity (meta-d'), controlling for political attitude (1: left; 9: right), gender (1 = male; 2 = female), age, and education (dummy-coded).

Predictor	*b*	*b* 95% CI	*beta*	*beta* 95% CI	Fit	Difference
(Intercept)	4.43**	[3.83, 5.02]				
d	0.25**	[0.12, 0.38]	0.17	[0.08, 0.26]		
Political Attitude	−0.09**	[−0.14, −0.03]	−0.14	[−0.23, −0.05]		
sex	−0.07	[−0.26, 0.12]	−0.03	[−0.12, 0.06]		
age	−0.00	[−0.01, 0.00]	−0.04	[−0.13, 0.05]		
education	0.01	[−0.06, 0.08]	0.01	[−0.08, 0.10]		
					$R^2 = 0.063$** 95% CI[0.02,0.10]	
(Intercept)	3.69**	[2.86, 4.52]				
d'	0.23**	[0.09, 0.36]	0.15	[0.06, 0.24]		
Political Attitude	−0.08**	[−0.14, −0.02]	−0.13	[−0.22, −0.04]		
sex	−0.02	[−0.21, 0.17]	−0.01	[−0.10, 0.08]		
age	−0.00	[−0.01, 0.00]	−0.06	[−0.15, 0.03]		
education	−0.01	[−0.08, 0.07]	−0.01	[−0.10, 0.08]		
confidence	1.05*	[0.23, 1.88]	0.12	[0.03, 0.21]		
					$R^2 = 0.076$** 95% CI[0.03,0.11]	$\Delta R^2 = 0.012$* 95% CI[−0.01, 0.03]
(Intercept)	3.75**	[2.91, 4.59]				
d'	0.22**	[0.08, 0.35]	0.15	[0.05, 0.24]		
polAttitude	−0.08**	[−0.14, −0.02]	−0.13	[−0.22, −0.04]		
sex	−0.01	[−0.20, 0.18]	−0.01	[−0.10, 0.08]		
age	−0.00	[−0.01, 0.00]	−0.06	[−0.15, 0.03]		
education	−0.01	[−0.08, 0.07]	−0.01	[−0.10, 0.08]		
confidence	0.92*	[0.04, 1.79]	0.10	[0.01, 0.20]		
meta-d'	0.08	[−0.09, 0.26]	0.05	[−0.05, 0.14]		
					$R^2 = 0.077$** 95% CI[0.03,0.11]	$\Delta R^2 = 0.002$ 95% CI[−0.01, 0.01]

Note. b represents unstandardized regression weights. *Beta* indicates the standardized regression weights. * indicates $p < .05$. ** indicates $p < .01$.

Table 3
Multiple regression analyses predicting belief that climate change is risky, using climate change knowledge, meta-knowledge (confidence), and metacognitive sensitivity (meta-d'), controlling for political attitude (1: left; 9: right); gender (1 = male; 2 = female), age, and education (dummy-coded).

Predictor	*b*	*b* 95% CI	*beta*	*beta* 95% CI	Fit	Difference
(Intercept)	4.23**	[3.69, 4.77]				
d'	0.19**	[0.07, 0.31]	0.14	[0.05, 0.23]		
Political Attitude	−0.11**	[−0.16, −0.05]	−0.19	[−0.28, −0.10]		
sex	−0.03	[−0.20, 0.14]	−0.02	[−0.10, 0.07]		
age	0.01*	[0.00, 0.01]	0.10	[0.02, 0.19]		
education	0.02	[−0.04, 0.09]	0.03	[−0.06, 0.12]		
					$R^2 = 0.080$** 95% CI[0.03,0.12]	
(Intercept)	3.24**	[2.49, 3.99]				
d'	0.16*	[0.04, 0.28]	0.12	[0.03, 0.21]		
Political Attitude	−0.10**	[−0.15, −0.05]	−0.17	[−0.26, −0.08]		
sex	0.04	[−0.13, 0.21]	0.02	[−0.07, 0.11]		
age	0.00	[−0.00, 0.01]	0.07	[−0.02, 0.16]		
education	0.00	[−0.07, 0.07]	0.00	[−0.09, 0.09]		
confidence	1.41**	[0.67, 2.15]	0.18	[0.08, 0.27]		
					$R^2 = 0.106$** 95% CI[0.05,0.15]	$\Delta R^2 = 0.026$** 95% CI[−0.00, 0.05]
(Intercept)	3.26**	[2.50, 4.01]				
d'	0.16*	[0.03, 0.28]	0.12	[0.02, 0.21]		
Political Attitude	−0.10**	[−0.15, −0.05]	−0.17	[−0.26, −0.08]		
sex	0.04	[−0.13, 0.21]	0.02	[−0.07, 0.11]		
age	0.00	[−0.00, 0.01]	0.07	[−0.02, 0.16]		
education	0.00	[−0.07, 0.07]	0.00	[−0.09, 0.09]		
confidence	1.38**	[0.59, 2.16]	0.17	[0.07, 0.27]		
meta-d'	0.02	[−0.14, 0.18]	0.01	[−0.08, 0.11]		
					$R^2 = 0.106$** 95% CI[0.05,0.15]	$\Delta R^2 = 0.000$ 95% CI[−0.00, 0.00]

Note. b represents unstandardized regression weights. *Beta* indicates the standardized regression weights. * indicates $p < .05$. ** indicates $p < .01$.

be the case in that the direction of the knowledge-belief association tended to be positive, and no evidence was revealed for a systematic change of that relationship across the political spectrum. Potential exceptions were extreme values of political attitude that do, however, render low cell sizes and large estimation error, and hence need to be interpreted with caution.

Study 1 highlighted the importance of confidence in knowledge (but not sensitivity of confidence) for explaining beliefs about the politicized subject of climate change. Specifically, climate change meta-knowledge predicted climate change beliefs above and beyond object-level

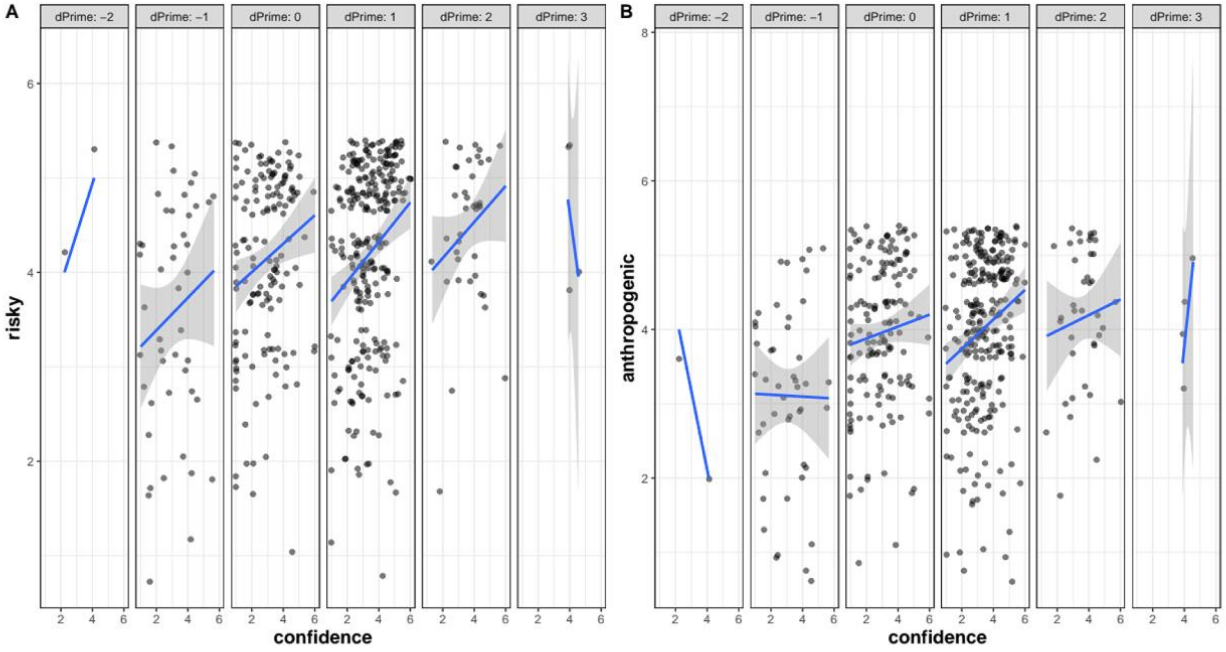

Fig. 2. Relationship between meta-knowledge (confidence) and climate change beliefs (risky, Panel A; anthropogenic, Panel B), for different levels of climate change knowledge (d', rounded). Dots represent individual participants. Shaded grey area denotes 95% CI.

knowledge. This held for both frequentist regression, and Bayesian regression, for both the belief that climate change is risky, and the belief that it is anthropogenic, and irrespective of political attitude.

Although these results clearly show that confidence in knowledge predicted climate change beliefs, they do not conclusively rule out two alternative explanations: (1) A confidence-belief link is not necessarily caused by *domain-specific* confidence. Rather, such a relationship could also be caused by more general mechanisms whereby participants with higher confidence in scientific knowledge in general also tend to have higher climate change beliefs (*confidence in science-knowledge explanation*); and (2) a confidence-belief link could also be caused by differences in response bias whereby participants who tend to use the high (low) end of the confidence scale, also tend to use the high (low) end of the climate change belief scales (*response-bias explanation*).

5. Study 2

Study 2 tested in how far study 1 results are domain-specific. Specifically, study 2 aimed at ruling out that confidence in science-knowledge could explain the relationship between confidence in climate change knowledge, and climate change beliefs. To do so, study 2 assessed knowledge and meta-knowledge in other-domain (biological and physical) science. If the degree of confidence in science knowledge explains climate change beliefs, we should find that other-science metacognitive confidence predicts higher climate change beliefs as well. To the extent that results of study 1 are domain-specific, however, metacognition of other-science knowledge should be less predictive of climate change beliefs compared to metacognition of climate change knowledge. Furthermore, to the extent that results are domain-specific, study 2 also rules out the response-bias explanation of study 1 results.

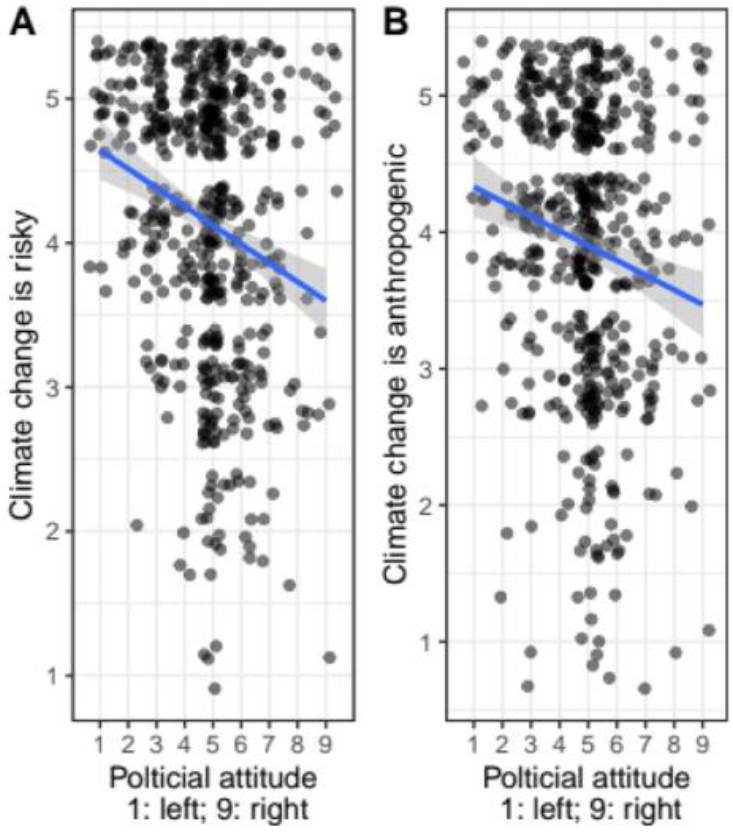

Fig. 3. Self-reported political attitude (left:1, right: 9) and climate change beliefs (risky, Panel A and anthropogenic, Panel B). Dots represent individual participants (with jitter for visibility). Shaded grey area represents 95% confidence band.

5.1. Methods

5.1.1. Participants

A total of $N = 588$ German citizens were recruited through the polling company YouGov. The sample constitutes a nationally balanced quota sample with respect to gender (female: $n = 303$, 51%), age (mean = 48.3, range = 18–88), and geographical distribution. Participants had a range of educational backgrounds, (lowest school leaving certificate: 15%; middle school leaving certificate: 36%; highest school leaving certificate: 23%; Bachelor: 8%; Master: 11%, PhD: 1%; other: 4%; fourteen participants did not indicate their education), and a wide range of professions.

5.1.2. Procedure

The procedure was identical to study 1.

5.1.3. Materials

To assess knowledge of biological and physical science, we used statements taken from the National Science Board's Science and Engineering Indicators. Participants judged a total of nine statements about general scientific facts in biology and physics (five TRUE, four FALSE): The center of the Earth is very hot. (True); The continents on which we live have been moving their locations for millions of years and will

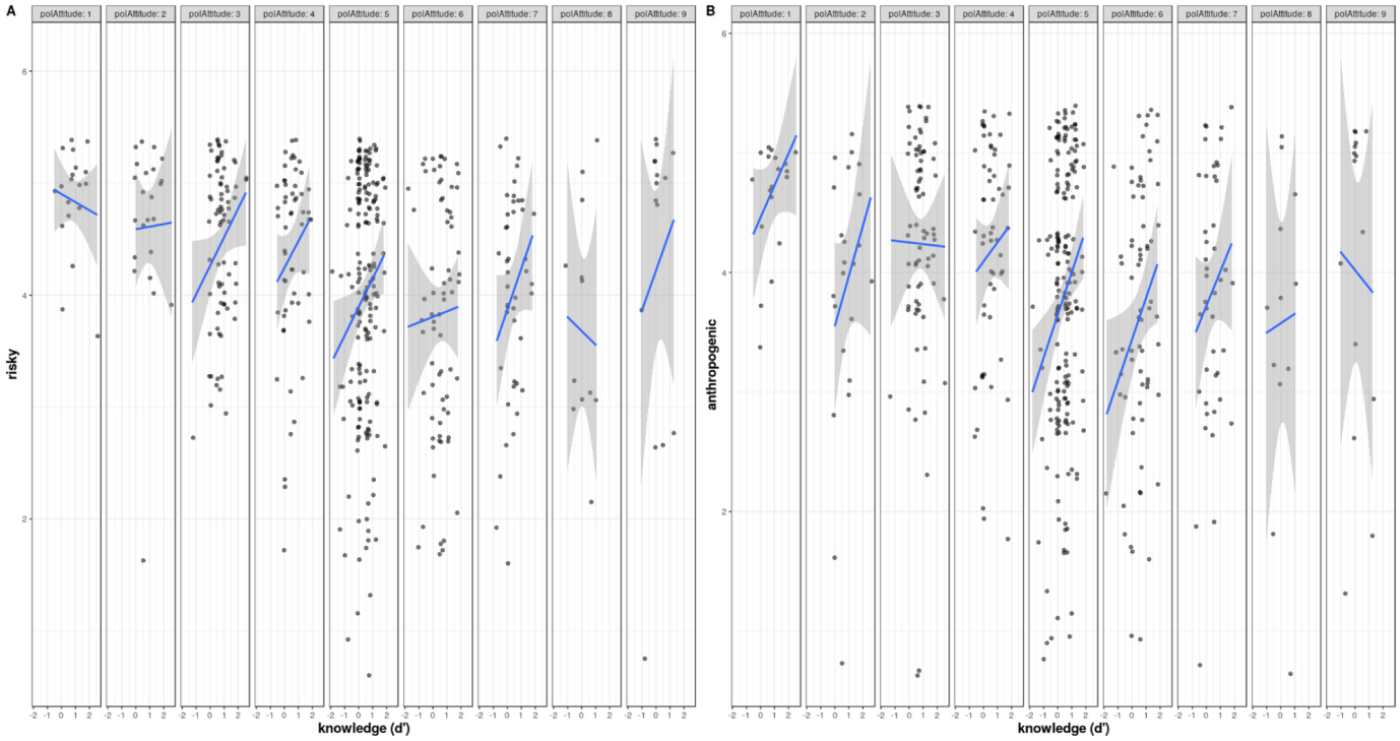

Fig. 4. Relationship between knowledge (d') climate change beliefs (risky, Panel A; and anthropogenic, Panel B) across the spectrum of political attitude (self-report; 1: left; 9: right). Dots represent individual participants. Shaded grey area denotes 95% CI.

continue to move in the future. (True); The Sun goes around the Earth. (False); All radioactivity is man-made. (False); Electrons are smaller than atoms. (True); Lasers work by focusing sound waves. (False); It is the father's gene that decides whether the baby is a boy or a girl. (True); Antibiotics kill viruses as well as bacteria. (False); The universe began with a huge explosion. (True).

5.1.4. Political orientation

Participants indicated "When talking about politics, one often hears the concepts 'left' and 'right'. We would like to know from you where you would place yourself" on a 7-point scale (1: left; 7: right).

5.1.5. Climate change beliefs

Participants indicated: "How much do you agree with the following statements: 1. "Climate change is mostly caused by humans" and. 2. "Climate change is risky", each on a 6-point scale ("1: I don't agree at all"; 6: "I totally agree"). The assessment of all other measures was identical to study 1.

5.1.6. Analysis

The computation of all indices was identical to study 1.

5.2. Results and discussion

Descriptive results on the distribution of political attitude and climate change beliefs is given in Fig. 5. Descriptive results for all measures used in study 2 are given in Table 4.

5.2.1. To what extent is the predictiveness of climate change meta-knowledge domain-specific?

To test in how far the result that climate change meta-knowledge predicted climate change beliefs is domain-specific, we conducted a combined analysis on both data sets produced by study 1 and 2 (total $N = 1097$) to test for interaction effects. If confidence in climate change, but not other-science knowledge predicts climate change beliefs, we should see an interaction between knowledge type (study 1: climate change knowledge versus study 2: other-science knowledge) and confidence in that knowledge. All continuous variables were z-transformed within each study, before being entered into joint regression models. We ran the same set of multiple regression models as in study 1, each predicting climate change belief (riskiness and anthropogenicity), with science knowledge (d'), political attitude, and demographic variables (gender, age, education) as the baseline model, and entering meta-knowledge (confidence) and sensitivity (meta-d'). Additionally, we entered two interaction terms: interaction between knowledge (d') and study in the baseline model to assess whether object-level climate change compared to other-science knowledge were differentially predictive of climate change beliefs, and, most importantly, interaction between knowledge type and confidence in knowledge to assess whether climate change meta-knowledge and other-science meta-knowledge were differentially related to beliefs (Table 5, Table 6). Concerning the baseline model, results replicated results from study 1 in that the baseline model, particularly political attitude, explained climate change beliefs. Furthermore, we found an interaction between knowledge and study for the belief that climate change is anthropogenic, but not the belief that climate change is risky, suggesting that climate change compared to other-science knowledge was more important for explaining beliefs about the anthropogenicity of climate change, but not for explaining beliefs about its risks.[1] Importantly, however, we found interactions between knowledge type and meta-knowledge for both beliefs. That is, climate change meta-knowledge was more predictive of both the belief that climate change is risky, and that it is anthropogenic compared to other-science meta-knowledge (Fig. 6). These results suggest that confidence in domain-specific knowledge relates to climate change beliefs more strongly compared to confidence in other-science knowledge.

[1] Analogous results were obtained when running the baseline model for study 2 data only: Other-science knowledge significantly predicted beliefs that climate change is risky ($b = 0.11$, $p < .05$), but not that it is anthropogenic ($b = 0.07$, $p = .27$).

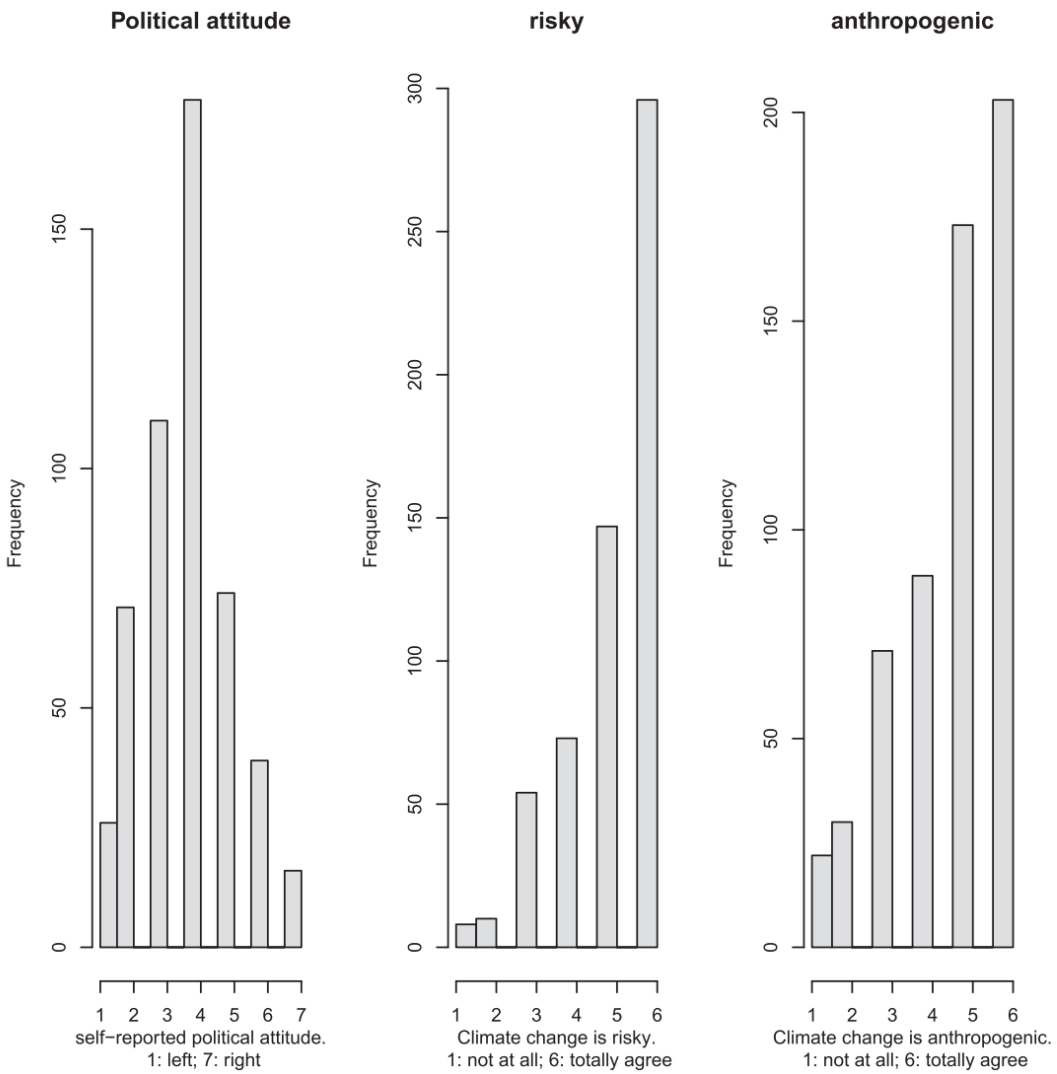

Fig. 5. Distributions of self-reported political attitude, beliefs that climate change is risky, and beliefs that climate change is anthropogenic for the sample used in study 2.

Table 4
Means, standard deviations, and correlations of measures used in study 2.

Variable	*M*	*SD*	1	2	3	4
1. anthropogenic	4.65	1.38				
2. risky	5.09	1.17	0.61** [0.56, 0.66] BF = 1.58e+58			
3. knowledge (d')	0.92 (range: −1.96 -2.66)	0.98	0.08 [0.00, 0.16] BF = 0.6	0.09* [0.01, 0.17] BF = 0.9		
4. meta-knowledge (confidence)	0.82	0.13	0.03 [−0.05, 0.11] BF = 0.1	0.10* [0.02, 0.18] BF = 2.2	0.46** [0.39, 0.52] BF = 1.82e+28	
5. meta-cognitive sensitivity (meta-d')	7.26	12.93	0.06 [−0.02, 0.14] BF = 0.3	0.12** [0.04, 0.20] BF = 7.1	0.52** [0.46, 0.58] BF = 2.12e+39	0.47** [0.41, 0.53] BF = 7.30e+30

Note. M and SD represent mean and standard deviation, respectively. Confidence scale represents values from 0.5 (50% confidence) to 1.0 (100% confidence). Values in square brackets indicate the 95% confidence interval. * indicates $p < .05$. ** indicates $p < .01$. BF: Bayes Factor.

Table 5
Multiple regression analyses predicting the belief that climate change is risky with other-science knowledge (d'), meta-knowledge (confidence), meta-cognitive sensitivity (meta-d') and interaction between study and confidence (study 1: climate change knowledge; study 2: other-science knowledge) as predictors, controlling for political attitude (1: left; 7: right); gender (1 = male; 2 = female), age, and education (dummy-coded).

Predictor	*b*	*b* 95% CI	Fit	Difference
(Intercept)	−0.18	[−0.43, 0.08]		
d'	0.20**	[0.08, 0.32]		
Political Attitude	−0.21**	[−0.27, −0.14]		
sex	0.06	[−0.06, 0.18]		
age	0.05	[−0.01, 0.12]		
education	−0.01	[−0.05, 0.04]		
study	0.07	[−0.09, 0.23]		
d':study	−0.12	[−0.27, 0.03]		
			$R^2 = 0.071$** 95% CI [0.04,0.10]	
(Intercept)	−0.14	[−0.39, 0.10]		
d'	0.09*	[0.01, 0.17]		
Political Attitude	−0.20**	[−0.26, −0.14]		
sex	0.11	[−0.01, 0.23]		
age	0.03	[−0.03, 0.09]		
education	−0.03	[−0.08, 0.02]		
confidence	0.20**	[0.11, 0.29]		
study	−0.00	[−0.12, 0.12]		
confidence: study	−0.14*	[−0.26, −0.01]		
			$R^2 = 0.089$** 95% CI [0.05,0.12]	$\Delta R^2 = 0.018$** 95% CI[0.00, 0.03]
(Intercept)	−0.13	[−0.38, 0.11]		
d'	0.07	[−0.01, 0.15]		
Political Attitude	−0.20**	[−0.26, −0.14]		
sex	0.12	[−0.01, 0.24]		
age	0.03	[−0.03, 0.09]		
education	−0.03	[−0.08, 0.02]		
confidence	0.20**	[0.12, 0.29]		
study	−0.03	[−0.16, 0.10]		
meta-d'	0.00	[−0.00, 0.01]		
confidence: study	−0.16*	[−0.29, −0.03]		
			$R^2 = 0.090$** 95% CI [0.05,0.12]	$\Delta R^2 = 0.001$ 95% CI[−0.00, 0.01]

Note. All continuous variables were z-transformed within each study, before being entered into regression models. * indicates $p < .05$. ** indicates $p < .01$.

Table 6
Multiple regression analyses predicting the belief that climate change is anthropogenic with other-science knowledge (d'), meta-knowledge (confidence), metacognitive sensitivity (meta-d') and interaction between study and confidence (study 1: climate change knowledge; study 2: other-science knowledge) as predictors, controlling for political attitude (1: left; 7: right); gender (1 = male; 2 = female), age, and education (dummy-coded).

Predictor	*b*	*b* 95% CI	Fit	Difference
(Intercept)	−0.18	[−0.45, 0.08]		
d'	0.23**	[0.11, 0.36]		
Political Attitude	−0.18**	[−0.24, −0.11]		
sex	0.05	[−0.07, 0.17]		
age	−0.04	[−0.10, 0.02]		
education	−0.00	[−0.05, 0.05]		
study	0.14	[−0.02, 0.30]		
d'*study	−0.19*	[−0.35, −0.04]		
			$R^2 = 0.057$** 95% CI [0.03,0.08]	
(Intercept)	−0.13	[−0.38, 0.13]		
d'	0.10**	[0.03, 0.18]		
Political Attitude	−0.18**	[−0.24, −0.12]		
sex	0.08	[−0.05, 0.20]		
age	−0.05	[−0.12, 0.01]		
education	−0.02	[−0.07, 0.03]		
confidence	0.14**	[0.05, 0.23]		
study	0.01	[−0.11, 0.14]		
confidence*study	−0.16*	[−0.29, −0.03]		
			$R^2 = 0.061$** 95% CI [0.03,0.08]	$\Delta R^2 = 0.003$ 95% CI[−0.00, 0.01]
(Intercept)	−0.13	[−0.38, 0.13]		
d'	0.10*	[0.02, 0.19]		
Political Attitude	−0.18**	[−0.24, −0.12]		
sex	0.08	[−0.05, 0.20]		
age	−0.05	[−0.12, 0.01]		
education	−0.02	[−0.07, 0.03]		
confidence	0.14**	[0.05, 0.23]		
study	0.02	[−0.12, 0.15]		
meta-d'	−0.00	[−0.01, 0.01]		
confidence*study	−0.16*	[−0.29, −0.02]		
			$R^2 = 0.061$** 95% CI [0.03,0.08]	$\Delta R^2 = 0.000$ 95% CI[−0.00, 0.00]

Note. All continuous variables were z-transformed within each study, before being entered into joint regression models. * indicates $p < .05$. ** indicates $p < .01$.

Study 2 investigated in how far the predictiveness of confidence in climate change knowledge for explaining climate change beliefs is domain-specific. Results showed that climate change, compared to other-domain meta-knowledge were differentially related to climate

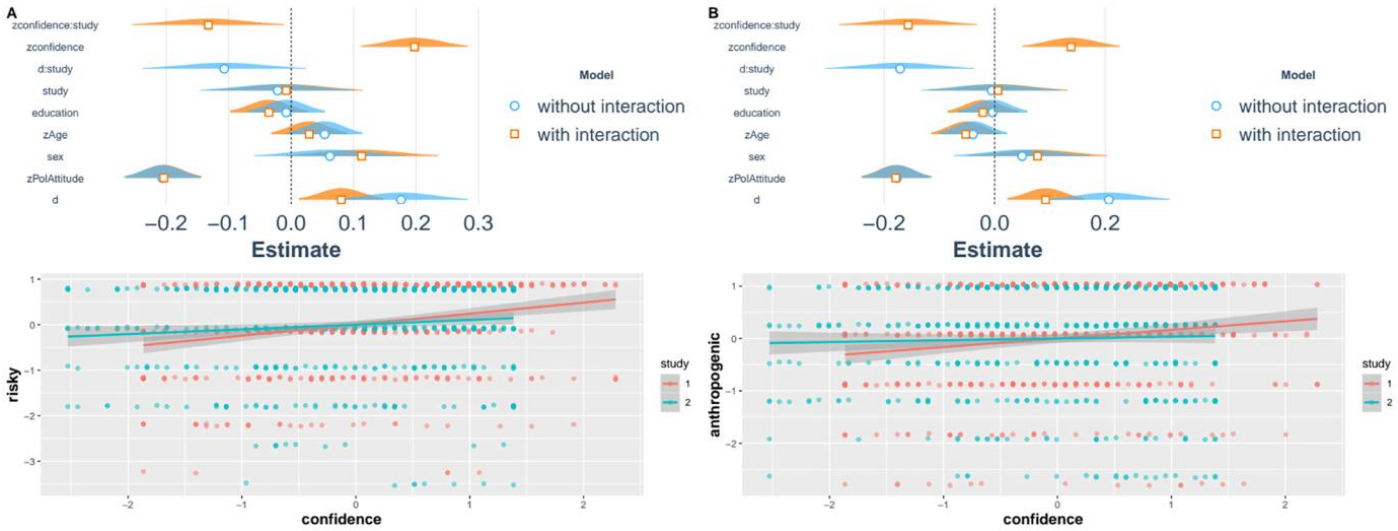

Fig. 6. Interaction between knowledge type (study 1: climate change knowledge; study 2: other-science knowledge) and meta-knowledge (confidence) for predicting climate change beliefs (risky, Panel A; anthropogenic, Panel B). Continuous variables are z-transformed. The top row displays the results of two regression models on the list of predictors used in both studies, one model with, and one model without an interaction term (study: confidence). The width of the distribution for each predictor indicates 95% CI. The bottom row visualizes the interaction between knowledge type and confidence for predicting climate change beliefs. Shaded grey area denotes 95% CI.

change beliefs. Specifically, confidence in climate change knowledge was more predictive of climate change beliefs compared to confidence in other-domain science knowledge. This result held for both the belief that climate change is risky, and the belief that climate change is anthropogenic. Taken together, study 2 results rule out the alternative, domain-general explanation whereby the degree of confidence in science knowledge in general explains climate change beliefs, as well as the response-bias explanation whereby tendencies to use high/low ends of response scales explain study 1 results. Study 2 hence suggests that climate change beliefs are shaped by domain-specific meta-knowledge. Or, conversely, that domain-specific meta-knowledge explains *knowledge-relevant* beliefs, beliefs built on that specific knowledge.

6. General discussion

Although considerable research exists on the role of object-level cognition for explaining beliefs about politicized science such as nanotechnology, vaccination, or climate change, the importance of meta-cognition is largely unknown. Here we investigate the relevance of meta-knowledge (or confidence in knowledge) for explaining beliefs about one of the most heavily contested examples: Climate change. Frequentist and Bayesian analyses showed that for a national German sample, climate change meta-knowledge was predictive of beliefs, above and beyond object-level climate change knowledge. These results held for both the belief that climate change is risky, and the belief that climate change is anthropogenic, and when controlling for well-known other predictors (political attitude, age, gender, education). Furthermore, for another national sample, we showed that the relationship between climate change meta-knowledge and climate change beliefs is domain-specific: Confidence in climate change knowledge was a stronger predictor of climate change beliefs compared to confidence in other-domain science knowledge, suggesting that outside of the context for which it was relevant, metacognitive confidence did not explain beliefs. These results highlight the relevance of domain-specific metacognition for explaining beliefs about the contested science of climate change.

Emerging evidence has demonstrated the relevance of domain-general metacognition for forming beliefs about political issues (Sinclair et al., 2020; Zmigrod et al., 2018, 2019), but it has also been argued that other, domain-specific facets of metacognition might be closer to the cognitive mechanisms that shape belief (Rollwage et al., 2018). In line with this proposition, we find a relationship between domain- specific meta-knowledge and climate change beliefs that is roughly the size of the relationship between object-level knowledge and beliefs. These results suggest that, for explaining beliefs about controversial science, metacognitive factors that are specific to the respective domain are roughly as important as understanding of the object-level matter itself.

These results contrast previous findings on the predictiveness of subjective knowledge. If subjective knowledge were simply a less reliable measure of objective knowledge, subjective measure should only add noise to objective measures, and subjective measures should not be able to explain variance above and beyond the variance explained by objective knowledge tests. The present results, however, suggest that when measured using entire scales, rather than using one-item assessment, subjective confidence in climate change knowledge is not simply a less reliable measure of objective knowledge; it is a different measure with explanatory value in its own right that captures additional aspects of knowledge that are not captured by objective tests alone. That is, while researchers have long argued, and rightfully so, that subjective self-report measures of knowledge do not constitute a reliable or valid proxy for objective knowledge tests (Roser-Renouf & Nisbet, 2008; van der Linden, 2017), the reverse may not hold, either—objective knowledge tests do not constitute a substitute for subjective self-report measures.

In addition to the higher reliability of entire confidence scales compared to one-item subjective knowledge measures, more cognitive mechanisms are likely at play that can help explain why climate change meta-knowledge delivers unique explanatory value. To this end, the question of what information confidence judgments are based upon appears most relevant. At least two different sets of models exist that seek to explain the cognitive basis of metacognitive judgments, direct-access views, and inferential views. According to direct-access views, metacognitive judgments are based on a direct readout of the respective object-level knowledge base, and hence predict a tight link between object-level and metacognitive accuracy. Inferential accounts, in contrast, posit that metcognitive judgments are based on various cues that can be only loosely related to the knowledge base (see Fleming & Dolan, 2012, for a review). Our results are arguably more in line with the second, inferential account, given that metacognitive confidence judgments constituted a unique predictor of climate change beliefs in

addition to object-level knowledge, which is more difficult to explain with an identical information base that both metacognitive and object-level judgments draw upon. Rather, when assessing confidence in climate change knowledge, participants might draw on a considerably larger knowledge base than what is assessed by the knowledge test. Such a broader knowledge base could, in principle, comprise knowledge about all previous encounters with information about climate change, and therefore comprise other, or more diverse exemplars of knowledge per knowledge domain. Furthermore, a broader knowledge base could entail entirely different knowledge domains that are not assessed in the respective objective knowledge test. In the present case, such knowledge domains might encompass action-related knowledge, knowledge abut the effectiveness and consequences of climate-related action (Tobler et al., 2012), or procedural knowledge, knowledge about the processes involved in climate science (Taddicken & Reif, 2016). A broader knowledge base could also encode additional information shown to affect climate change beliefs, such as the credibility of the source of the information (Cook & Lewandowsky, 2016). To the extent that confidence judgments are based on a more comprehensive search of memory content, they will, almost by necessity, explain other aspects of differences in climate change beliefs than what is explained by knowledge tests alone.

Future research could systematically explore which cues (if any) are stored alongside the seemingly "clean" true/false statements commonly used in knowledge tests, and how these additional cues shape meta-cognitive judgments. For example, research has found that consensus messaging, informing the public about the high scientific consensus on climate change, can affect beliefs about the anthropogenicity of climate change, and its risks (van der Linden, Leiserowitz, Feinberg, & Maibach, 2015). If consensus information is stored as an additional, meta-scientific cue alongside the respective piece of climate change knowledge, this might not only affect object-level beliefs and belief updating (Jern, Chang, & Kemp, 2014), but could also affect the degree of confidence with which the knowledge is held, and thereby also impact judgments and beliefs built on that knowledge.

Some researchers have argued that in heavily politicized information environments, understanding of the scientific domain (broadly understood as scientific literacy or numeracy) might not be sufficient to foster public beliefs that are consistent with the science. Rather, higher understanding of the science could even exacerbate societal polarization over the science by enabling more cognitively reflective citizens to use their skills to engage in motivated reasoning (Kahan et al., 2012), or enabling citizens with higher numeracy to interpret evidence selectively such that it confirms their cultural and political worldviews (Kahan, Peters, Dawson, & Slovic, 2017). In line with this reasoning, US citizens with the highest degree of scientific literacy and numeracy were amongthe most heavily polarized over the risks of climate change (Kahan et al., 2012), and more scientific literate citizens tended to be more heavily polarized over the anthropogenicity of climate change (Drummond & Fischhoff, 2017).

It is noteworthy, however, that these results mostly stem from US samples, while considerably less is known about a potentially polarizing effect of scientific knowledge for non-US samples. Here we show for two independent national German samples, that while climate change was politicized in that political attitude was related to climate change be-liefs, evidence for a polarizing effect of knowledge was weak. Specifically, climate change knowledge tended to be positively related to climate change beliefs across the political spectrum. A potential exception were extreme ends of the political spectrum, where the knowledge-belief link was weaker. However, these cases rendered small cell sizes and large prediction error and should therefore be interpreted with caution. Furthermore, a weaker knowledge-belief relationship was evident at both ends of the spectrum, that is, not specific to conservatives. These results highlight the need for non-US samples to reveal the full spectrum of nuances involved in a potentially polarizing effect of scientific knowledge across societies.

In previous work into domain-*general* metacognition (measured with low-level perceptual discrimination), metacognitive sensitivity explained politically radical beliefs above and beyond task performance and confidence (Rollwage et al., 2018). This constitutes an interesting divergence from the present results where sensitivity of confidence, albeit showing a first-order relationship with climate change beliefs in the order of [0.05, 0.22] and [0.06, 0.23] (for anthropogenicity and risk, respectively), did not explain climate change beliefs when controlling for knowledge, political attitude, and confidence. An obvious difference between both studies pertains to the type of judgments as either about the accuracy of low-level perception, or the accuracy of prior knowledge. A vast majority of research has demonstrated the construction of memory in light of current world views in general (Chew, Huang, & Zhao, 2019; Saucet & Villeval, 2019; Schacter & Coyle, 1997), as well as the potentially inferential nature of metacognitive judgments more specifically (see Koriat, 2007, for a review). Although this is for future research to decide, motivated memory effects may be less likely when judging the accuracy of low-level perception compared to judgments about the accuracy of one's climate change knowledge. Hence, the (objective) accuracy of metacognitive judgments might be less relevant for explaining climate change beliefs compared to the (subjective) confidence with which they are made.

The present research that takes a metacognitve perspective on politicized science complements recent work on psychological inoculation against misinformation as a way of shaping confidence. Specifically, preemptively informing, "inoculating", citizens about common misinformation techniques (such as using emotional language, or spreading conspiracy theories) increased not only citizens' ability to correctly assess the reliability of misinformation, but also increased the confidence that citizens had in their reliability judgments (Basol, Roozenbeek, & van der Linden, 2020). Furthermore, inoculation messages could protect the positive effect of consensus messages against a subsequent, real-world disinformation campaign contesting the existence of a scientific consensus (van der Linden, Leiserowitz, Rosenthal, & Maibach, 2017). Increasing the accuracy of confidence in verifications of false versus scientifically accurate information is particularly important in the area of politicized climate science. This is because the accuracy of confidence in own verifications of true and false statements has been shown to be lower for climate science compared to areas of general, non-politicized science, and lower than necessary based on the accuracy of citizens' object-level knowledge (Fischer et al., 2019).

Two conclusions can be drawn, one methodological, and one theoretical. Methodologically, first, the present results suggest that just like subjective measures of climate change knowledge do not constitute a reliable and valid substitute of objective knowledge tests, so do objective knowledge tests not constitute a comprehensive substitute of subjective assessment. Rather, both objective tests, and subjective self-report measures provide unique variance, and should be used to more comprehensively explain climate change beliefs. Theoretically, second, the present results highlight the importance of domain-specific meta-knowledge for explaining beliefs about the contested issue of climate change. By demonstrating the relevance of metacognitive, rather than solely object-level thought, these results add to our understanding of the cognitive processes involved in the formation of beliefs about politicized science.

Declaration of Competing Interest

None.

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