Politicized climate science: No evidence for science literacy driving motivated reasoning, or polarized belief-updating in a US national experiment

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Abstract

A substantial literature demonstrates public polarization over climate change, particularly among the science literate. The dominant explanation for this phenomenon is that science literacy amplifies directional motivated reasoning, the tendency to interpret evidence such that it confirms desired conclusions. However, the evidence regarding this biasing account of science literacy is inconclusive. The present study tests the biasing account of science literacy in a national survey experiment among the U.S. population. Although results replicated the typical correlational pattern of political polarization as a function of science literacy, results delivered little support for the core causal claim of the biasing account—that science literacy drives motivated reasoning, and polarized belief-updating. First, results delivered little evidence that science literacy amplified motivated reasoning, despite strong motivated reasoning effects. And second, results delivered little evidence that science literacy amplified polarized belief-updating. That is, the science literate were polarized, but science literacy was not polarizing. These results help clarify the role of science literacy for public beliefs about contested science.

Keywords. Motivated reasoning, Climate change, Belief updating, science literacy, politicized science

A substantial body of research demonstrates public polarization over climate change along ideological and partisan lines in the United States (Ballew et al., 2019; Bohr, 2014; Dunlap et al., 2016; McCright & Dunlap, 2011). Somewhat counterintuitively, this polarization tends to be most pronounced among the science literate (Drummond & Fischhoff, 2017; Hart et al., 2015; Kahan et al., 2012). A dominant explanation for this phenomenon is that science literacy amplifies, rather than mitigates, directional motivated reasoning, the tendency to interpret evidence such that it confirms a desired conclusion (Bayes & Druckman, 2021). Science literacy, it is argued, endows one with the ability to directionally interpret uncongenial evidence such that it protects social identity, endorses ideology, or confirms prior beliefs (Hart et al., 2015; Hornsey, 2020, 2021; D. M. Kahan, 2015; D. M. Kahan et al., 2017; Pasek, 2018), thereby reinforcing polarization. The biasing account has been widely influential, both in science communication (Kahan, 2012), and science for policy (see research for European Parliament’s Committee on Culture and Education; (Siarova et al., 2019). Despite its impact, however, causal evidence for biasing account is surprisingly weak. Here, we put the biasing account of science literacy to an experimental test encompassing both motivated reasoning and belief-updating in one common study. This allows us to test the extent to which science literacy relates to polarized climate change beliefs *because of the purported causal mechanism*—science literacy drives motivated reasoning, and subsequent polarized belief-updating.

Reasoning about climate change is often directionally motivated, desired to align with a congenial goal. Reasoning about climate change therefore often does not result in accurate conclusions, but is more reflective of one’s worldviews, or political identity: “politically motivated reasoning is not truth-convergent” (Kahan, 2015). Numerous studies have demonstrated directionally motivated reasoning in relation to climate change, ranging from motivated perception of weather anomalies as a function of prior climate change beliefs (Howe, 2018), motivated interpretation of climate news (Hart & Nisbet, 2011), or climate graphs (Luo & Zhao, 2019) as a

function of political orientation, and selective exposure to environmental news coverage as a function of ideological and political dispositions (Feldman & Hart, 2018; Hennessy et al., 2017).

Critically, according to the biasing account, science literacy amplifies standing tendencies of motivated interpretation of climate change evidence. The purported cognitive mechanism is that the more knowledgeable individuals are of the topic, the better equipped they are at arguing away uncongenial evidence (Hornsey, 2021; Kahan, 2012; Kahan et al., 2012). The idea that reasoning capacity exacerbates, rather than mitigates, motivated reasoning was arguably most famously put forth in Kahan and colleagues (2012). This study reported an interaction between science literacy and worldviews: Among US adults adhering to an egalitarian worldview, science literacy was positively correlated with concern about climate change risks; among individuals adhering to a hierarchical worldview, however, this correlation was negative. This correlational finding was later attributed to “the power of motivated reasoning” (Kahan, 2012). Similar interactions between measures of knowledge or skill, and political leaning were found in several large, national surveys (Drummond & Fischhoff, 2017; Hamilton, 2011; Hamilton et al., 2015; Malka et al., 2009; McCright & Dunlap, 2011), as well as experimental studies on topics of worldview, such as gun control, immigration or Brexit (Guay & Johnston, 2020; Kuru et al., 2017; Sumner et al., 2018; Taber & Lodge, 2006).

Other researchers conceptualized science literacy in a markedly different manner, as part of a view of human rationality as fostering sound judgment (Miller, 2012; Morais, 2018; Priest, 2013; Shtulman & McCallum, 2014; Theodosiou, 2019). This view sees science literacy not as driving motivated interpretation of evidence, and political polarization, but--quite the opposite--, as critical for citizens and societies to deal with complex problems such as climate change. Specifically, it is argued that science literacy helps citizens navigate information in digital media environments, making informed decision based on the best available evidence, and avoiding science-related misinformation (Howell & Brossard, 2021; Miller, 2012). There is no consensus in the literature on

whether science literacy fulfills that promise, however, although arguably related evidence on domain-specific knowledge, or cognitive sophistication has often yielded results that contradict the biasing account (Fischer & Said, 2020; McPhetres & Pennycook, 2019; Ranney & Clark, 2016; Van der Linden, 2015).

In sum, the biasing account has received considerable coverage in science communication (D. Kahan, 2012), and policy briefs (Siarova et al., 2019). Although evidence from cross-sectional designs aligns with the biasing account (Ballew et al., 2020; Bohr, 2014; Drummond & Fischhoff, 2017; McCright & Dunlap, 2011b), evidence directly testing the purported causal mechanism—science literacy drives motivated reasoning and subsequent polarized belief-updating—is surprisingly rare, and there is yet no clear consensus in the literature on its validity. This lacking consensus is reflected in recent reviews that reach conflicting conclusions, either aligning with (Hornsey, 2021), or contradicting core assumptions of the biasing account (Bayes & Druckman, 2021; Druckman & McGrath, 2019). Furthermore, several studies in favor of the biasing account (Guay & Johnston, 2020; Kuru et al., 2017; Sumner et al., 2018; Taber & Lodge, 2006) either come from matters of worldview (Guay & Johnston, 2020; Kuru et al., 2017; Sumner et al., 2018; Taber & Lodge, 2006) that cannot necessarily be generalized to matters of science.

The present research

The present research provides a comprehensive test of the core causal assumption of the biasing account of science literacy in a U.S. survey experiment: Does science literacy drive motivated interpretation of climate change evidence, and subsequent polarized belief-updating? We combined an experimental design where citizens evaluated climate change evidence, with the classical belief-updating paradigm (Lord et al., 1979; Taber & Lodge, 2006). Citizens repeatedly evaluated evidence supporting or contradicting anthropogenicity, and their belief-updating was assessed. This allowed us to investigate (i) cross-sectional patterns of polarization, (ii) biased

interpretation of scientific evidence (*motivated reasoning*), and (iii) within-participants belief-updating in one, common design. This study extends existing evidence in three crucial aspects.

First, only when investigating both motivated reasoning and polarized belief-updating in one common study, can we determine the extent to which motivated reasoning causes the pattern of polarized climate change beliefs found in national surveys (Ballew et al., 2020; Bohr, 2014; Drummond & Fischhoff, 2017; McCright & Dunlap, 2011b). This entails, further, that a valid test should provide (within-participants) evidence that beliefs polarize as a function of prior beliefs or worldviews, rather than explaining (cross-sectional) polarized belief patterns with motivated reasoning *post hoc* (Kahan et al., 2012). If the biasing account holds, science literacy should reinforce tendencies to interpret the provided climate change evidence such that it supports prior beliefs or political ideology, and individuals who show this biased interpretation of evidence (motivated reasoning) should, by and large, also show polarized belief-updating.

Second, errors in evaluating evidence are driven by two distinct cognitive mechanisms, the *ability* to correctly discern different types of evidence, and the *motivation* to classify evidence as supporting or contradicting anthropogenic climate change, irrespective of evidence. For example, the same overall proportion of errors in evidence evaluations, could be driven by lacking ability to perceive differences in evidence, or by the inclination to label all evidence as contradicting anthropogenicity. Here, we employ Signal detection theory (SDT) which affords a method to decouple motivation (*response bias* or *decision threshold*, c) from ability (*sensitivity*, d'). Decoupling sensitivity and bias provides greater clarity to an ongoing ambiguity in the literature regarding *how* science literacy might bias reasoning (if at all): Science literacy could shift decision thresholds (e.g., by affecting the social or emotional “costs” of classifying evidence as supporting vs. contradicting anthropogenicity), or affect the ability to discern different types of evidence (Roberts & Bybee, 2014), or both. Rather than simply analyzing to what extent science literacy

affects evidence evaluations, SDT, therefore, provides insight into the cognitive underpinnings of these effects.

Third, leveraging SDT allows us to shed light on the debate around the *asymmetry hypothesis*, the notion that cognitive biases in processing of evidence are asymmetrical across the political spectrum. Republicans and Conservatives were repeatedly shown to hold climate change beliefs that contradict scientific consensus (for a meta-analysis, see Hornsey et al., 2016). These and similar results, for example concerning human evolution (Hamilton, 2015), or vaccination (Hornsey et al., 2020; Motta, 2021), have reinforced the notion that conservatives may be disproportionately biased in the processing of scientific information that contradicts their worldviews (Lewandowsky et al., 2020). Conversely, other research has concluded that while worldviews generally bias reasoning, these effects are *symmetrical* along the political spectrum, that is, equally strong for Conservatives and Liberals (or Democrats and Republicans). This notion is supported by studies showing that Liberals and Conservatives were equally likely to deny counterattitudinal scientific evidence (Washburn & Skitka, 2018), and showed no evidence for asymmetries in information-processing (Guay & Johnston, 2020). Leveraging SDT, we investigate whether the cognitive ability to discern different types of evidence (sensitivity, d'), and the inclination to label evidence as supporting vs. contradicting anthropogenicity (response bias, c) are asymmetrical across the political spectrum.

Methods

Transparency and Openness. All data, analysis code (R), and material for this study are available under <https://osf.io/crxt9/>. The design of this study was preregistered under https://aspredicted.org/see_one.php. The study was approved by the Ethical Review Board of University of the Leibniz-Institut für Wissensmedien (Leibniz Institute for Knowledge Media),

Tübingen. We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study.

Participants. A total of $N = 762$ US citizens were recruited through the polling company YouGov. The sample constituted a nationally balanced quota sample with respect to gender (female: $n = 412$, 54%), age (18-24: $n=70$; 25-34: $n= 132$; 35-44: $n=121$; 45-54: $n= 112$; >55: $n= 327$), and state. Participants had a range of educational backgrounds (No High School: $n=31$; High school graduate $n=256$; Some college: $n=187$; 2-year college: $n= 72$; 4-year college: $n=136$; Postgraduate education: $n=80$).

This sample size is sufficient to detect small effects of $r = .15$ with 90% power at $\alpha = 0.5$ in regression models comprising five main effects, and one interaction term (with low correlation between both interacting variables; science literacy—prior belief: $r=0.01$; science literacy—party affiliation: $r=-0.04$; science literacy—ideology: -0.13), and was determined prior to data collection in our preregistered study design.

Material. Participants read a total of eight summaries of studies about climate change. The summaries varied in the direction of evidence: either supporting or rejecting the anthropogenicity of climate change (four summaries supporting, four summaries rejecting). Four of the summaries about climate change were adapted versions taken from previous research (Fryer, Harms & Jackson, 2019, Said, Fischer & Anders, 2021), the other four summaries were newly developed for the present study. Summaries were structured as following: (a) two introductory sentences describing the aim of the study. (b) three to four sentences about the findings of the study, and (c) one final sentence stating the conclusion of the study findings. On average summaries consisted of 110 words (90-127 words).

Procedure. The study was completed in the following order: Party affiliation; Political ideology; Science Literacy; Prior Beliefs; Summaries; Posterior Beliefs; and Debriefing. Demographics (age, education and gender) were separately assessed by the panel provider.

Presentation of the summaries was partially randomized. That is, summaries were randomly allotted to four blocks, with each block containing two summaries of the same evidence (supporting or contradicting). The order of the four blocks was then randomized. Participants indicated their evaluation of the evidence after each summary. Participants indicated their current belief about whether or not climate change is anthropocentric after each block, that is, four times in total.

Measures

Science literacy. Analogously to prior research (Kahan et al., 2012), science literacy was assessed with ten items from the National Science Foundation's (NSF) Science and Engineering Indicators. Participants indicated "Please indicate whether the following statements are true or false" (true/false). The list of items was: The center of the Earth is very hot; The continents on which we live have been moving for millions of years and will continue to move in the future; The continents on which we live have been moving for millions of years and will continue to move in the future; All radioactivity is man-made; Electrons are smaller than atoms; Lasers work by focusing sound waves; It is the father's gene that decides whether the baby is a boy or a girl; Antibiotics kill viruses as well as bacteria; The Universe began with a huge explosion.

Party affiliation. Participants indicated "Which of the following describes your party affiliation best?" on a 7-point scale (Strong Democrat, Democrat, Independent lean Democrat, Independent, Independent lean Republican, Republican, Strong Republican).

Ideology. Participants indicated "Which of the following describes your political ideology best?" on a 5-point scale (Very liberal, Liberal, Moderate, Conservative, very Conservative).

Prior and posterior climate change beliefs. Participants indicated "Do you think human activity is the cause of increasing temperatures?", on a 17-point scale ranging 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).

Evidence evaluation. After each summary participants indicated “This summary provides evidence that ... ” on a 17-point scale ranging from -8 (human activity is NOT the cause of increasing temperatures) to 8 (human activity is the cause of increasing temperatures).

Signal Detection Theoretic measures. We also measured the accuracy of evidence evaluation as sensitivity (d') and response bias (c) as specified in Signal Detection Theory (SDT). Sensitivity (d') measures individuals' ability to discern two types of evidence, supporting and contradicting anthropogenic climate change. The higher sensitivity, the better participants are at categorizing evidence correctly. Sensitivity is quantified as the difference between the z-transformed True Positive (Hit) rate, and the z-transformed False Positive (False Alarm) rate, $z(\text{TP}) - z(\text{FP})$, of all evidence evaluations. Answers were coded such that Hits refer to correctly classifying evidence supporting anthropogenic climate change as supporting. Optimal sensitivity is $d' = 3$.

Response bias (c) measures individuals' tendency to give one type of response in the evidence evaluation task, that is, to evaluate evidence as either supporting, or contradicting anthropogenic climate change, irrespective of evidence. *Bias* is quantified as $-1/2 * (z(\text{True Positive}) + z(\text{False Positive}))$. Positive values of *bias* denote a tendency to classify evidence as contradicting anthropogenicity, irrespective of evidence (by producing relatively few False Alarms, and relatively many Misses); negative values denote a tendency to classify evidence as supporting anthropogenicity (by producing relatively many False Alarms, and relatively few Misses). Optimal bias is $c = 0$, denoting unbiased classification of evidence.

To compute sensitivity and response bias, we treated each evaluation of evidence as either correct or incorrect. For evidence supporting anthropogenicity, responses > 0 were treated as correct (and all other responses as incorrect); for evidence contradicting anthropogenicity, responses < 0 were coded as correct (and all other responses as incorrect).

Polarization. Polarization was quantified as the extent to which participants updated their beliefs in the direction of their prior beliefs, that is, the extent to which posterior (compared to

prior) beliefs were more skeptical of anthropogenicity for those who were initially skeptical (prior beliefs <0), and the extent to which posterior (compared to prior) beliefs were more supportive of anthropogenicity for those who were initially non-skeptical (prior beliefs >0). Values from participants who were initially undecided (prior beliefs $=0$), that is, who only formed an opinion on anthropogenicity in response to the presented evidence, were excluded from the analysis ($n = 55$, 0,14%).

Analytical strategy

We used linear mixed-effects models employing the R-package *lmer*, as well as Bayesian linear models employing the R package *stan_lmer*. Our default regression model included the same set of covariates (prior belief, gender, age, and education), and science literacy. When testing interactions between science literacy and worldview variables (party affiliation, ideology), we tested one interaction term per regression model, and both interacting variables were included as main effects. Linear mixed-effects models were fitted with individuals participants and evidence direction (supporting vs. contradicting anthropogenicity) as random effects. Fitting random intercept for each participant helps remove within-subjects correlations that could otherwise bias results. Specifically, the following model syntax was used for fitting linear mixed effects:

Baseline model: $y \sim \text{gender} + \text{age} + \text{education} + \text{prior belief} + (1|\text{subject}) + (1|\text{condition}) + \epsilon$.

Full model: $y \sim \text{political attitude} * \text{scientific literacy} + \text{gender} + \text{age} + \text{education} + \text{prior belief} + (1|\text{subject}) + (1|\text{condition}) + \epsilon$.

Bayesian linear models perform full Bayesian estimation, rather than maximum likelihood estimation. For analysis we used Markov chain Monte Carlo (MCMC) sampling with four chains of 1000 samples and 1000 burn-in steps each. For prior choice, the default priors of the *rstanarm* package were used:

Prior	Distribution
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Regression coefficients	Normal
Intercept	Normal
Auxiliary parameters	Exponential

For the Bayesian regression, all reported parameter estimates are the median of the posterior distribution, together with 95% CI, and Bayes Factors (BF). Bayes Factor provide the evidence strength for the degree to which the data support either the null, or the alternative hypothesis. Values > 1 provide increasing support for H1 compared to Ho, values < 1 provide increasing support for Ho compared to H1. For interpretation, we followed the heuristic given in Jeffreys (1961), where BFs 1–3 are interpreted as anecdotal evidence, 3 – 10 as substantial, 10–30 as strong, 30–100 as very strong, and BFs > 100 as decisive evidence for H1, and the same values used as denominators in fractions of 1 (1/3, 1/10 etc.) denote the evidence strength for H0. We report both *Bayes Factors* and *p*-values since Bayes Factors provide less evidence against the null hypothesis than the corresponding *p*-value (Held & Ott, 2018), and hence reporting Bayes Factors only could be considered to unduly reduce the likelihood of results in favor of the biasing account of science literacy.

Results

Descriptive results. Means, standard deviations, and correlations of the main variables of this study are displayed in Table 1.

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

Variable	M	SD	1	2	3	4	5
1. Prior climate change belief	11.60	5.03					

2. Party affiliation	3.72	2.03	-.51**				
			[-.56, -.46]				
3. Ideology	2.88	1.19	-.52**	.68**			
			[-.57, -.47]	[.64, .72]			
4. Science Literacy	1.26	1.07	.01	-.04	-.13**		
			[-.06, .08]	[-.11, .03]	[-.20, -.06]		
5. Evidence evaluation: sensitivity (d')	0.45	1.12	.20**	-.11**	-.14**	.21**	
			[.13, .26]	[-.18, -.04]	[-.21, -.07]	[.14, .28]	
6. Evidence evaluation: response bias (c)	-0.34	0.77	-.60**	.38**	.36**	.10**	.05
			[-.64, -.55]	[.32, .44]	[.30, .42]	[.03, .17]	[-.02, .12]

Note. Values in square brackets indicate the 95% confidence interval for each correlation. * $p < .05$. ** $p < .01$. *Party affiliation*: Strong Democrat--strong Republican. *Ideology*: Very liberal--very conservative.

Cross-sectional results: Are climate change beliefs polarized as a function of science

literacy? Analogously to prior research (Drummond & Fischhoff, 2017; D. M. Kahan et al., 2012), we investigated the relationship between science literacy and prior climate change beliefs (climate change is anthropogenic), separately per political attitude (strong Democrat—strong Republican) and ideology (very liberal—very conservative). As Figure 1 shows, party affiliation and ideology strongly moderated the relationship between science literacy and prior climate change beliefs in this cross-sectional analysis. We found extreme evidence for the interactions of science literacy with party affiliation, $BF = 992$, and very strong evidence for an interaction with ideology, $BF = 73$ (see Supplementary Table S1 for all regression coefficients). The relationship between science literacy and belief relationship was weaker for Democrats and Liberals, compared to Republicans and Conservatives, mirroring the pattern of results found in Kahan (2012). Citizens with the highest

degree of science literacy were the ones with the biggest gap in beliefs, resulting in the typical “funnel shape” found previously (Drummond & Fischhoff, 2017).

Figure 1. Cross-sectional pattern of prior beliefs (climate change is anthropogenic) as a function of science literacy and A: party affiliation (Strong Democrat/Democrat/Independent lean Democrat and Strong Republican/Republican/Independent lean Republican collapsed for visibility) or B: political ideology.

Does science literacy amplify motivated evaluation of evidence? We first investigated whether individuals showed evidence of directional motivated interpretation of evidence. Motivated reasoning should manifest in shifting the direction of evidence (supporting vs. contradicting anthropogenicity) as a function of prior beliefs, party affiliation, or ideology. We regressed the evaluation of evidence on our default set of predictors (set of covariates, and science literacy), and tested for interactions between science literacy, and prior belief, party affiliation or ideology.

Results delivered extreme evidence in favor of motivated evidence evaluation in all models. There were main effects of prior belief, party affiliation and ideology, both for evidence supporting, all $BF > 100$, as well as contradicting anthropogenicity, all $BF > 100$.

We next explored whether science literacy amplified this motivated evaluation of evidence. If the biasing account holds, we should find an interaction between science literacy, and prior beliefs, party affiliation, or ideology. However, this is not what we found. Bayesian regression results delivered very strong evidence in favor of an *absence* of interaction of science literacy with prior belief, $BF = 0.46$, party affiliation, $BF = 0.031$, as well as ideology, $BF = 0.033$, for evidence supporting anthropogenicity. Likewise, for evidence contradicting anthropogenicity, results showed very strong evidence in favor of an *absence* of interaction of science literacy with prior belief $BF = 0.061$, and substantial evidence in favor of an absence of interaction with party affiliation, $BF = 0.17$, and ideology, $BF = 0.19$ (see Supplementary Tables S2 and S3 for all regression coefficients).

Furthermore, in contrast to the predictions of the biasing account, results provided strong and very strong evidence for negative main effects of science literacy in two of the three models for evidence contradicting anthropogenicity (party affiliation and ideology), $BF=24.6$ and $BF=32.2$, and anecdotal evidence for positive main effects of science literacy in two of the models supporting anthropogenicity, $BF = 2.36$ and $BF = 2.12$ (party affiliation and ideology). These results suggests that, if anything, science literacy related to more *accurate* interpretations of evidence in these cases, even when controlling for prior beliefs, education, or political leaning.

Results of the linear mixed-effects models were largely in line with those of the Bayesian regression. In particular, we did not find significant interactions of science literacy with prior prior beliefs, $b = -.08$, 95%CI [-0.66-.5], $b = .05$, 95%CI [0.23-.12]; party affiliation $b = .05$, 95%CI [0.23-.12], or ideology $b = .05$, 95%CI [0.23-.12] (for evidence supporting and contradicting anthropogenicity, respectively). We did, however, find highly significant main effects of science

literacy in the direction of the to-be interpreted evidence, suggesting that science literacy related to more accurate evidence interpretation (see Fig. 2 for all coefficients).

Jointly, these results contradict a core prediction of the biasing account of science literacy: Science literacy drives motivated reasoning. Instead, Bayesian analyses provide extreme evidence in favor of an absence of interactions of science literacy with prior beliefs, party affiliation, and ideology, despite extreme evidence in favor of overall motivated evidence evaluations. Furthermore, science literacy partially exerted main effects signifying more accurate evidence evaluations.

Figure 2. Regression coefficients from the linear mixed-effects models predicting evidence evaluation, separately for evidence supporting (Pro), and contradicting (con) anthropogenicity. The three models test interactions of science literacy with prior belief (climate change is anthropogenic), party affiliation (strong Democrat—strong Republican), or Ideology (Very liberal—very conservative). All coefficients standardized. Robust standard errors used to find confidence intervals.

How does science literacy relate to interpretation of evidence? Signal detection

theoretic results. To gain deeper insights into the cognitive mechanisms underpinning evidence evaluations, we tested in how far science literacy predicted sensitivity (d') and response bias (c) of evidence evaluations. Sensitivity and bias were regressed on the default list of predictors in three regression models, testing for main effects of prior belief, party affiliation, and ideology, and their respective interactions with science literacy.

Concerning sensitivity (d'), Bayesian regression results provided strong and substantial evidence for a positive main effect of prior beliefs in two of the three models (party affiliation and ideology), $BF = 12.8$ and $BF = 3.6$, respectively, indicating that citizens with higher, compared to lower, climate change beliefs were better able to discern different types of evidence, when controlling for political leaning. This relationship was not moderated by science literacy, however. Rather, results delivered anecdotal evidence in favor of an absence of interaction with prior belief, and very strong evidence in favor of an absence of interaction with party affiliation, $BF = 0.04$, and ideology, $BF = 0.06$. These results suggests that first, the sensitivity of evidence discernment was lower for participants with lower climate change beliefs, but this relationship was unaffected by science literacy (see Supplementary Table S4 for all regression coefficients).

Concerning response bias (c), results delivered extreme evidence for main effects of prior beliefs, $BF > 100$, party affiliation, $BF > 100$, and ideology, $BF > 100$, such that the placement of the decision criterion to classify evidence as supporting, or contradicting anthropogenicity varied as a function of prior beliefs, party affiliation, and ideology. However we found no evidence that this bias was amplified by science literacy. Rather, results delivered strong evidence in favor of an absence of interaction of science literacy with prior belief, $BF = 0.05$, party affiliation, $BF = 0.05$, and ideology, $BF = 0.08$.

In sum, signal detection theoretic results provide strong evidence that sensitivity of evidence evaluation was related to prior beliefs (when controlling for political leaning), and extreme evidence

that bias was related to prior beliefs, party affiliation, and ideology. However, results provided no evidence that science literacy amplified these relationships.

Asymmetry or symmetry of bias? Group-level comparison of response bias (c). To investigate in how far motivated reasoning effects were symmetrical across the political and ideological spectrum, we analyzed both the (signed) response bias (c), as well as the absolute (unsigned) level of response bias. As shown in Figure 5, the same pattern of results emerged across different measures of worldviews: The *sign* of the response bias was more positive for skeptics, Republicans, and Conservatives, indicating a tendency to classify evidence as contradicting anthropogenicity, irrespective of evidence (and vice versa for non-skeptics, Democrats, and Liberals). The *size* of the bias, however, did not differ as a function of worldviews. Rather, results delivered substantial evidence in favor of equal bias across levels of skepticism, $BF=0.18$, very strong evidence across party affiliation, $BF=0.02$, and extreme evidence across ideology, $BF=0.008$. That is, in line with the symmetry hypothesis, citizens were equally biased, irrespective of prior climate change beliefs, party affiliation, or ideology—only in different directions.

Figure 4. Signal detection theoretic analyses of the response bias (c) of evidence evaluations, per climate skepticism (non-skeptic: prior belief >0 , skeptic: prior belief ≤ 0), party affiliation (strong Democrat, Democrat and strong Republican, Republican collapsed for visibility), and ideology (very liberal—very conservative). The figure compares the (signed) response bias (c), as well as the absolute (unsigned) level of response bias, $\text{abs}(c)$. Horizontal lines denote the median, red dots denote the mean.

Does science literacy foster polarized belief-updating? The biasing account predicts that citizens with higher science literacy are more prone to polarized belief-updating as a function of prior beliefs, party affiliation or political ideology. We predicted polarization from the default regression model (set of covariates, science literacy, and respective interactions with prior belief, party affiliation, and ideology). Bayesian regression results provided no evidence that science literacy fostered polarized belief-updating. Rather, results provided strong evidence in favor of an absence of interaction of science literacy with prior belief, $\text{BF} = 0.07$, and party affiliation, $\text{BF} = 0.03$ (Fig. 5, and see Supplementary Table S5 for all regression coefficients). Notably, results did

deliver anecdotal evidence in favor of an interaction with ideology. However, this interaction was negative, and hence in the opposite direction of what would be predicted by the biasing account—as science literacy increased, the relationship between ideology and polarization *decreased*. Hence, if anything, higher science literacy prevented polarization among the more politically conservative.

Linear mixed-effects models produced largely converging results. Most importantly, all interactions with science literacy were non-significant. Probably the best evidence in favor of the biasing account comes from statistically significant positive main effect of science literacy in two of the three models predicting polarization (prior belief and ideology), suggesting more science literate citizens were more likely to polarize in these cases. These results, however, provide anecdotal evidence *against* this effect in the Bayesian regression model, $BF = 0.6$ and $BF=0.99$.

Figure 5. Belief-updating over all rounds, per science literacy (low, med, high), and skepticism (skeptical: prior beliefs ≤ 0 ; non-skeptical: prior beliefs > 0), party affiliation, and ideology.

Figure 6. Regression coefficients from the linear-mixed effects models predicting polarization. Three models tested interactions of science literacy with prior belief (climate change is anthropogenic), party affiliation (strong Democrat—strong Republican), or Ideology (Very liberal—very conservative). All coefficients are standardized. Robust standard errors were used to find confidence intervals.

How frequent is polarized belief-updating? And does it follow from motivated interpretation of evidence? Participants were classified as polarizing when their beliefs became more extreme (i.e., who updated their posterior beliefs in the direction of the prior beliefs) as “polarizer” (Taber & Lodge, 2006). Polarization was a rare, and also weak phenomenon. A group of $n=144$ (19%) participants polarized, compared to $n=315$ (41%) who did not update their beliefs at all, and a total of $n=248$ (33%) participants who de-polarized that is, who had less extreme posterior, compared to prior, beliefs (Participants who were initially undecided, prior beliefs = 0; 0.14% were excluded from this analysis).

Furthermore, motivated reasoning did not appear as a strong causal driver of polarization. Rather, polarization was only weakly related to motivated reasoning: Out of $N = 559$ citizens who displayed motivated reasoning, interpreting the evidence as either supporting, or contradicting anthropogenic climate change, irrespective of evidence, less than one quarter ($n = 122$; 22%) polarized. Even among those citizens who were most prone to motivated reasoning (response bias $\geq$ mean +1SD), only 26% polarized ($n=62$). Importantly, however, of the $N = 144$ citizens who did polarize, the vast majority ($n = 122$; 84%) had shown motivated reasoning. These results suggest that rather than motivated reasoning driving polarization, a common—other--factor drives both motivated reasoning and polarized belief-updating.

Discussion

The present study found little evidence to support the notion that science literacy causally drives motivated reasoning or polarized belief-updating over climate change, although we did replicate the typical cross-sectional pattern demonstrating stronger political polarization among the science literate (Drummond & Fischhoff, 2017; Hamilton, 2011; Hamilton et al., 2015). We draw three key conclusions from this study. First, science literacy did not amplify motivated reasoning, despite strong motivated reasoning effects as a function of prior beliefs, party affiliation and ideology. In fact, Bayesian results provided strong evidence against a moderating effect of science literacy on motivated reasoning. Second, polarization was not only a rare and weak phenomenon, it was also not amplified by science literacy. Results provided strong evidence against a moderating effect of science literacy, and, if anything, the relationship between political ideology and polarization *decreased* as science literacy increased. Lastly, the relationship between motivated reasoning and subsequent polarized belief-updating was weak, and motivated reasoning did not, for the vast majority of citizens, drive polarization. Even among citizens who showed the highest level of motivated reasoning, only 26% actually polarized.

Science literacy did not amplify motivated evaluations of climate change evidence. This held even though evidence evaluations were heavily biased in the direction of worldviews, suggesting that the provided evidence was politically contentious. A lacking interaction with science literacy is hence particularly telling in the present case that yielded strong partisan and worldview effects on how citizens perceived scientific evidence. In fact, if anything, science literacy was related to more *accurately* evaluating evidence supporting anthropogenicity as supporting, and evidence contradicting anthropogenicity as contradicting. These results suggest that, despite strong worldview effects, science literacy stood out as a unique, positive predictor of correctly interpreting contentious evidence. These effects of science literacy mirror emerging evidence highlighting the beneficial, rather than harmful, effects of the related construct of digital media literacy (Guess et al., 2020; Kahne & Bowyer, 2017) on citizens' ability to evaluate contented evidence in partisan information environments.

Furthermore, this study failed to provide evidence that science literacy amplifies polarized belief-updating. Results provided strong evidence in favor of an absence of interactions of science literacy with prior belief, and party affiliation. In the one case of ideology, where results did provide some evidence in favor of an interaction with science literacy, it was in the opposite direction of the prediction of the biasing account: as science literacy increased, the relationship between ideology and polarization decreased. Polarization was also a rare (19% of participants polarized) and weak phenomenon compared to de-polarization ($M_{\text{belief-change}} = 1.95$ vs. $M_{\text{belief-change}} = 4.37$). Lastly, motivated reasoning was not a strong driver of polarized belief-updating: Even among citizens showing the highest level of motivated reasoning, only 26% subsequently polarized.

Signal detection theoretic results provided greater clarity about the cognitive mechanisms behind evidence evaluations. Citizens with climate skeptic prior beliefs tended to achieve lower *sensitivity* (d'), demonstrating that they were less able to discern evidence that supports anthropogenicity, from evidence that contradicts it. These results are noteworthy because they

demonstrate that prior beliefs are linked to the mere *ability* to classify evidence correctly. Motivated reasoning probably cannot explain these effects since motivated reasoning should affect response bias, but not sensitivity (Batailler et al., 2021). Rather, the lower sensitivity among climate skeptics may be driven by the specific characteristics of the media and information environments of climate skeptics that challenges expert knowledge, and climate science (Adam et al., 2020; Elgesem et al., 2015; Sharman, 2014), which may blur the line between correct and incorrect pieces of knowledge (Fischer et al., 2019) different types of evidence. This is consistent with recent evidence showing that Conservatives had lesser abilities to discern true from false political claims, which could partially be explained with the political implications of these claims (Garrett & Bond, 2021).

Evidence is often (if not typically) ambiguous. It is therefore necessary to establish a standard for how strong evidence needs to be in order to be perceived as evidence in favor of one position (e.g., anthropogenicity of climate change), rather than the other (natural causes of climate change). This standard, called decision threshold or response bias in SDT, was reflective of worldviews: Citizens with lower prior climate change beliefs, Republican party affiliation, and more conservative political ideology were more likely to classify evidence as contradicting anthropogenicity, irrespective of evidence—and vice versa. Albeit a prime candidate for motivated reasoning, however, this tendency to directionally shift decision thresholds, was not amplified by science literacy.

Civic science literacy has been deemed a prerequisite for informed individual, and collective decision-making about science-related topics (Howell & Brossard, 2021), as critical to the preservation of democratic principles (Miller, 2012), and a “21st century skill” (Turiman et al., 2012). Other researchers have argued that, quite the contrary, science literacy amplifies public division, and opinion polarization by exacerbating motivated interpretation of evidence (Kahan et al., 2012, 2017). This lack of consensus about the role of science literacy is particularly relevant in digital information environments that confront citizens with a high proportion of *noise*, fabricated

evidence, or information of unclear, and mixed truth value, particularly so on contentious science (Benegal & Scruggs, 2018; Cook, 2019; Farrell, 2018; Treen et al., 2020). It is of high practical and theoretical importance to have clarity about the role of science literacy for dealing with evidence in these cases. One of the key results from the present study is that when confronted with mixed evidence on climate change, science literacy did not amplify motivated interpretation of evidence, despite strong tendencies to evaluate evidence such that it aligns with one's worldviews. Instead, the higher science literacy, the more accurate citizens' evaluations of evidence. These results lend support to the notion that being able to critically reflect on a topic helps citizens make sound judgment (Pennycook & Rand, 2019, 2021), rather than amplifying the social divide.

There is disagreement in the literature of whether cognitive bias is, or is not, politically symmetrical (Baron & Jost, 2019; Ditto et al., 2019). The asymmetry hypothesis rests on a substantial literature demonstrating cognitive asymmetries along the political spectrum (Jost, 2017; Jost et al., 2018; Morisi et al., 2019), arguably the most controversial of which is that conservatism relates to closed-minded reasoning, resistance to belief-updating in response to uncongenial information, and lower integrative complexity and cognitive reflection (Baron & Jost, 2019; Price et al., 2015; Sinclair et al., 2020; Vraga, 2015). Other researchers, however, failed to provide evidence for the asymmetry hypothesis and argued that worldviews do bias information-processing, but not necessarily asymmetrically so (Ecker et al., 2021; Frimer et al., 2017; Washburn & Skitka, 2018; Zmigrod et al., 2019). We find support for both hypotheses in the present study. Supporting the symmetry hypothesis, Liberals and conservatives (or Democrats and Republicans), tended to interpret evidence such that it confirmed their desired outcomes; however, the absolute extent of this bias was equal. In other words, partisanship and political ideology related to motivated interpretation of evidence—only in different directions. Supporting the asymmetry hypothesis, however, the sensitivity to discern different types of information varied as a function of prior

beliefs. The more climate skeptic citizens were when judging the evidence, the less able they were to correctly discern evidence supporting anthropogenicity from evidence contradicting it.

To conclude, the present results cast doubt on the ubiquity of the biasing account of science literacy. While cross-sectional climate change beliefs were polarized along partisan and ideological lines among the US population--and particularly so among the science literate--, repeated-measures analyses delivered evidence against the purported causal mechanism driving this pattern: Science literacy drives motivated reasoning and subsequent polarized belief-updating. Science literacy was not a major source of motivated interpretation of evidence, nor of motivated belief-updating. In other words, the science literate were polarized, but science literacy was not polarizing. Instead, if anything, higher science literacy was related to more accurate evidence evaluations. By finding little evidence to support the biasing account in a comprehensive study, these results add to our increasing understanding of the role of science literacy for citizens' ability to evaluate evidence about divisive science.

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Supplementary Material

Supplementary Table S1. Coefficients of the Bayesian linear model predicting prior climate change belief (climate change is anthropogenic) from the list of covariates (gender, age, education), and testing for interactions of science literacy with party affiliation, or ideology.

<i>Predictors</i>	Party affiliation		Ideology	
	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>
Intercept	15.36	13.53 – 17.23	15.99	14.11 – 17.91
Party affiliation	-0.83	-1.10 – -0.56		
Science Literacy	1.07	0.43 – 1.70	1.27	0.55 – 2.00
gender	0.86	0.15 – 1.55	0.81	0.18 – 1.42
age	-0.50	-0.73 – -0.26	-0.33	-0.57 – -0.10
education	0.06	-0.18 – 0.30	0.05	-0.18 – 0.27
Party affiliation * Science literacy	-0.33	-0.49 – -0.17		
Ideology			-1.42	-1.85 – -0.99
Ideology * Science literacy			-0.56	-0.81 – -0.32
Observations	646		707	
R ² Bayes	0.310		0.315	

Supplementary Table S2. Coefficients of the Bayesian linear model predicting evidence evaluations of evidence supporting anthropogenicity from the list of covariates (gender, age, education), and testing for interactions of science literacy with prior belief, party affiliation, or ideology.

<i>Predictors</i>	Prior belief		Party affiliation		Ideology	
	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>
Intercept	5.20	3.65 – 6.69	6.48	5.03 – 7.93	6.22	4.55 – 7.95
CC_Prior_Belief	0.54	0.46 – 0.63	0.52	0.46 – 0.57	0.53	0.47 – 0.58
Science Literacy	0.07	-0.53 – 0.70	0.28	-0.17 – 0.73	0.36	-0.22 – 0.91
gender	0.15	-0.34 – 0.61	0.14	-0.33 – 0.60	0.15	-0.32 – 0.60
age	-0.07	-0.23 – 0.11	-0.05	-0.21 – 0.12	-0.04	-0.21 – 0.13
education	-0.02	-0.18 – 0.15	-0.05	-0.21 – 0.11	-0.04	-0.21 – 0.12
CC_Prior_Belief:dprime_ScientificLiteracy	0.02	-0.03 – 0.06				
Party affiliation			-0.25	-0.44 – -0.06		
Party affiliation * Science literacy			-0.00	-0.12 – 0.11		
Ideology					-0.28	-0.63 – 0.05
Ideology * Science literacy					-0.05	-0.23 – 0.15
Observations	646		646		646	
R ² Bayes	0.497		0.507		0.503	

Supplementary Table S3. Coefficients of the Bayesian linear model predicting evidence evaluations of evidence contradicting anthropogenicity from the list of covariates (gender, age, education), and testing for interactions of science literacy with prior belief, party affiliation, or ideology.

<i>Predictors</i>	Prior belief		Party affiliation		Ideology	
	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>
Intercept	3.40	1.24 – 5.53	4.56	2.50 – 6.64	5.07	2.67 – 7.41
CC_Prior_Belief	0.43	0.31 – 0.54	0.39	0.31 – 0.47	0.39	0.31 – 0.46
Science Literacy	-0.99	-1.88 – -0.11	-1.77	-2.40 – -1.18	-1.97	-2.72 – -1.21
gender	-0.00	-0.69 – 0.68	0.01	-0.66 – 0.69	0.01	-0.66 – 0.69
age	0.08	-0.17 – 0.32	0.09	-0.15 – 0.33	0.10	-0.14 – 0.32
education	0.05	-0.17 – 0.28	0.05	-0.18 – 0.28	0.04	-0.18 – 0.26
CC_Prior_Belief:dprime_ScientificLiteracy	-0.03	-0.09 – 0.04				
Party affiliation			-0.21	-0.46 – 0.06		
Party affiliation * Science literacy			0.13	-0.02 – 0.29		
Ideology					-0.42	-0.88 – 0.04
Ideology * Science literacy					0.23	-0.02 – 0.49
Observations	646		646		646	
R ² Bayes	0.256		0.260		0.260	

Supplementary Table S4. Coefficients of the Bayesian linear model predicting sensitivity (d') of evidence evaluations from the list of covariates (gender, age, education), and testing for interactions of science literacy with prior belief, party affiliation, or ideology.

<i>Predictors</i>	Prior belief		Party affiliation		Ideology	
	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>
Intercept	0.10	-0.38 – 0.58	0.10	-0.38 – 0.58	0.10	-0.38 – 0.58
Prior belief	0.03	0.00 – 0.06	0.03	0.00 – 0.06	0.03	0.00 – 0.06
Science Literacy	0.21	0.01 – 0.40	0.21	0.01 – 0.40	0.21	0.01 – 0.40
gender	0.03	-0.12 – 0.17	0.03	-0.12 – 0.17	0.03	-0.12 – 0.17
age	-0.03	-0.08 – 0.03	-0.03	-0.08 – 0.03	-0.03	-0.08 – 0.03
education	-0.02	-0.07 – 0.04	-0.02	-0.07 – 0.04	-0.02	-0.07 – 0.04
Prior belief * Science literacy	-0.00	-0.02 – 0.01	-0.00	-0.02 – 0.01	-0.00	-0.02 – 0.01
Observations	646		646		646	
R ² Bayes	0.071		0.071		0.071	

Supplementary Table S5. Coefficients of the Bayesian linear model predicting polarization from the list of covariates (gender, age, education), and testing for interactions of science literacy with prior belief, party affiliation, or ideology.

<i>Predictors</i>	Prior belief		Party affiliation		Ideology	
	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>	<i>Estimates</i>	<i>CI (95%)</i>
Intercept	-0.68	-2.46 – 1.01	-0.89	-2.63 – 0.83	-2.62	-4.54 – -0.82
CC_Prior_Belief	-0.02	-0.11 – 0.07	-0.01	-0.07 – 0.05	0.01	-0.05 – 0.07
Science Literacy	0.35	-0.33 – 1.06	0.67	0.18 – 1.17	1.31	0.68 – 1.94
gender	-0.45	-1.00 – 0.09	-0.45	-0.96 – 0.07	-0.47	-1.01 – 0.05
age	0.00	-0.19 – 0.20	0.00	-0.19 – 0.20	-0.02	-0.21 – 0.17
education	0.02	-0.18 – 0.20	0.01	-0.17 – 0.20	0.02	-0.16 – 0.20
CC_Prior_Belief:dprime_Scienti ficLiteracy	0.01	-0.04 – 0.06				
Party affiliation			0.03	-0.18 – 0.24		
Party affiliation *			-0.05	-0.18 – 0.08		
Science literacy						
Ideology					0.57	0.20 – 0.95
Ideology * Science literacy					-0.28	-0.49 – -0.07
Observations	646		646		646	
R ² Bayes	0.039		0.041		0.055	