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NUMERACY PREDICTS ACCURATE CLIMATE CHANGE KNOWLEDGE AND BELIEFS: A MODEL OF FACTORS THAT INFLUENCE BIASES AND POLARIZATION

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NUMERACY PREDICTS ACCURATE CLIMATE CHANGE KNOWLEDGE AND BELIEFS:
A MODEL OF FACTORS THAT INFLUENCE BIASES AND POLARIZATION

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Abstract

Although 97% of experts generally agree that modern global warming is largely caused by human activities, some people hold biased, inaccurate beliefs about the causes of climate change and the strength of the scientific consensus. Numeracy skills, which are among the strongest predictors of decision making quality and risk literacy (i.e., the ability to evaluate and understand risk), theoretically should help reduce climate-related biases and polarization. However, some studies suggest that numeracy may ironically be associated with small yet significant increases in belief biases among people who strongly identify with specific cultural worldviews. While suggestive, these studies have not assessed the potential confounds associated with differences in knowledge. Accordingly, this paper presents the first two studies to address previous limits and test a cognitive model of the structural relations among numeracy, worldviews, knowledge, beliefs, and climate risk perceptions. Converging results from Study 1 (i.e., probabilistically representative national sample, n = 305) and Study 2 (i.e., diverse adult U.S. residents, n = 537) revealed that numeracy is generally associated with robust direct and indirect positive predictive links with climate change knowledge, beliefs, and risk attitudes. On average, highly numerate people were about 4 times more likely than less numerate people to have accurate knowledge and beliefs, and about 3 times more likely to express above average relative risk concerns. Numeracy's protective influence was fully mediated by differences in knowledge, which was by far the strongest predictor of accurate beliefs and risks attitudes (e.g., 5-40 times stronger association with knowledge than cultural worldviews). Biases associated with cultural worldviews were also found to be largely but not entirely mediated by differences in knowledge (e.g., individualists tended to be less knowledgeable than egalitarians). Overall, findings are consistent with mechanisms described in Skilled Decision Theory and highlight the robust link between numeracy skills (e.g., risk literacy) and acquisition of accurate knowledge and beliefs (e.g., representative understanding) that tends to protect against cognitive vulnerability and judgment biases. Discussion also considers implications of the lack of interactions on attitude polarization, and the need for integrated modeling of cognitive skills and knowledge as a routine part of the development of accurate and transparent risk and science communication.

Keywords: Numeracy, Risk Literacy, Knowledge, Climate Change

NUMERACY PREDICTS ACCURATE CLIMATE CHANGE KNOWLEDGE AND BELIEFS: A MODEL OF FACTORS THAT INFLUENCE BIASES AND POLARIZATION

Chapter 1: Introduction

The global temperature is more than 1°C higher on average than pre-industrial levels, according to Intergovernmental Panel on Climate Change. Defined as "an increase in combined surface air and sea surface temperatures averaged over the globe and over a 30-year period" (Allen et al., 2018, p. 51), global warming is likely to have major, enduring implications for many human activities including public health, labor, and ecosystems (e.g., more than $420 billion cost projected in 2090; EPA, 2017). Although research suggests that there is strong expert consensus about anthropogenic global warming (e.g., 97%), some people have inaccurate beliefs about climate change and scientific consensus, which could have major social and economic consequences (e.g., personal and public risk action for mitigation; Hayhoe et al., 2018; Leiserowitz et al., 2020). Research suggests that factors such as cultural worldviews may enhance polarization in risk attitudes via motivated reasoning processes that bias information searches, reasoning, and decision making. Ironically, although cognitive skills (e.g., numeracy) generally promote more accurate knowledge and beliefs, some initial evidence has suggested that numeracy may interact with cultural worldviews to enhence biases. If correct, this interaction could potentially promote rather than protect against the acquisition of biased knowledge, beliefs, or attitudes about climate change (Kahan et al., 2012, 2017). To date, however, although knowledge is a well-established determinant of accurate climate beliefs and judgments, research has yet to assess the role of climate change knowledge in studies linking numeracy and biases (Ding et al., 2011; Hornsey et al., 2016; Kobayashi, 2018; Lewandowsky et al., 2013; van der Linden et al., 2015c). Will numeracy protect against or further promote the polarizing effects of cultural worldviews in more comprehensive studies that include assessments of the powerful influence of climate change knowledge?

Cultural Worldviews, Biases, and Motivated Reasoning

According to the Cultural Theory of Risk, people's cognitive processes may often be influenced by the degree to which people identify themselves with specific cultural worldview orientations (e.g., hierarchy, individualism, egalitarianism, and fatalism; Douglas & Wildavsky, 1982). Although there are nuanced and varied interpretations, the theory broadly holds that cultural worldviews are functionally similar to psychological notions of human values that tend to be related to robust differences in motivational goals (Corner et al., 2014; Steg & Sievers, 2000; van der Linden, 2015c). Accordingly, research has demonstrated that brief psychometric scales designed to measure trait-like cultural worldviews and value orientations may help explain differences in judgments and attitudes about diverse risks and related issues (e.g., climate change beliefs). For example, when considering risks of various environmental issues (e.g., global warming, nuclear power) research suggests that individualism and hierarchy may generally be associated with moderately polarized lower perceived risk as compared to the somewhat higher than average perceived risks reported by participants with egalitarian worldviews (Douglas & Wildavsky, 1982; Jones, 2011; Xue et al., 2014).

Theoretically, among other influences, differences in cultural worldviews may in some cases be linked to biased cognitive processing via mechanisms of *motivated reasoning*. In this context, motivated reasoning refers to the notion that people's deeply held desires, values, and beliefs may consciously or unconsciously bias various aspects and stages of cognitive processing in ways that protect and promote specific conclusions, regardless of the accuracy of resulting implications, beliefs, or conclusions (Kunda, 1990). For example, Kahan and colleagues (2011) examined the relationship between cultural worldviews and processing of new information in the context of expert consensus about diverse risks including global warming. Participants were given

vignettes where fictional experts from different domains (i.e., global warming, gun control, nuclear waste) systematically expressed their expert opinions about each risk in ways that were either congruent or incongruent with typical worldview beliefs or attitudes (e.g., systematically presented expert opinions as higher/lower risk, independent of actual expert consensus or ecologically valid claims). When participants were then asked to rate how strongly they agreed or disagreed that the described expert was trustworthy and knowledgeable, participants' evaluation was found to be a partially predictable product of the congruency between the reported experts' position and one's purported cultural worldview. For instance, when the fictional expert suggested that the risk of global warming was high, a higher percentage of egalitarian communitarians agreed that the expert was both trustworthy and knowledgeable, as compared to the lower-than-expected ratings reported by hierarchical individualists (Kahan et al., 2011).

While the function of cultural worldviews is not necessarily associated with cognitive biases, previous empirical research findings and related theory has suggested that biased motivated reasoning processes may often amplify bias and polarized attitudes. It has been further suggested that the potential influence of motivated reasoning may be especially likely to manifest whenever biased processing is necessary to protect or enhance one's own identity as a member of a worldview group (Kahan et al., 2007, 2011, 2017; Sherman & Cohen, 2006). Thus, people who report identifying as hierarchical individualists, and who in turn benefit from this affiliation, may be more likely to increase biased information acquisition via motivated reasoning, thereby amplifying the strength of their own biased understanding and agreement about inaccurate facts (e.g., "I've seen multiple experts and politicians on the news say that climate change isn't caused by humans so there can't be consensus among scientists"). In contrast, individuals who identify more as communitarian egalitarians may be likely to develop more polarized views that reflect

their own self-serving biases and inaccurate beliefs, which may exaggerate the strength of the evidence in the opposite way (e.g., "every qualified climate scientist that appears in my social media feed always agrees without exception").

Taken together, the research suggests that individuals' cultural worldviews may be usefully described as fundamental values that tend to manifest as relatively stable, quantifiable psychological traits. As such, brief psychometric instruments designed to measure these traits can predict people's judgments, beliefs, and risk attitudes in meaningful ways. At an extreme, theory and data also indicate that individuals who have strongly held cultural worldviews may be more vulnerable to biases and attitude polarization that often results from motivated cognition in part because they have a greater stake in rejecting information that threatens their strongly held values and identity. As such, they may be especially likely to engage in processes that promote biases and polarization when faced with contentious issues.

Numeracy and Knowledge

Recent research and experiments indicate that having knowledge about the existence of expert consensus regarding anthropogenic global warming tends to causally reduce biases and may limit polarization among climate change risk attitudes of educated adults (Lewandowsky et al., 2013; van der Linden et al., 2015c). Given the importance and influence of accurate knowledge, it seems likely that skills and experiences associated with knowledge acquisition and effective reasoning should be likely to have meaningful associations with individual differences in climate science knowledge. For example, statistical numeracy skills (e.g., practical probabilistic math and reasoning skills) have been found to be among the single best predictors of general decision making skills and risk literacy (i.e., the ability to evaluate and understand risks) among educated individuals (Cokely et al., 2012, 2018; Ghazal et al., 2014). In addition to many examples of the

benefits of numeracy for effective reasoning, decision making, and knowledge acquisition in socially and economically important domains (e.g., health, wealth, relationships), there is also a small number of recent studies showing beneficial associations between numeracy and decision making in climate and weather domains. For instance, numerate individuals are less vulnerable to myths (i.e., widespread but incorrect information based on folk science) about tornadoes (Allan et al., 2017). A study that examined the judgment of people who lived in areas vulnerable to tornado events suggested that numerate individuals tended to be less likely to believe in inaccurate knowledge about tornadoes and effective personal risk mitigation strategies (i.e., tornado myths). Similarly, a study on flood risk literacy indicated that numeracy predicted having more knowledge about the risks of floods and the benefits of various risk mitigation strategies. A subsequent study found that some key benefits of flood risk literacy followed primarily from the fact that people with higher numeracy skills tended to identify and acquire more accurate knowledge about future flood risks as compared to less numerate individuals from the same region (Ramasubramanian et al., 2019).

According to Skilled Decision Theory, numeracy skills, particularly those associated with statistical numeracy and probabilistic reasoning, are thought to confer benefits via skilled cognitive and affective heuristic deliberation processes. Although heuristic and intuitively-grounded reasoning processes can in some cases promote biased reasoning and knowledge acquisition, the profound benefits of integrated knowledge and *representative understanding* are generally so important for decision making that they tend to outshine any risks (e.g., a child who has diligently practiced chess for 10 years is much more likely to make good chess-related decisions compared a Nobel prize winning scientist who is only a novice chess player). For example, research has shown that numeracy skills tend to be associated with differences in the precision and clarity of

one's memory of objective information and of one's subjective feelings about the risks, as has been demonstrated in the link between many kinds of risky prospect evaluations such as ignoring a heart attack, maximizing financial returns, understanding social norms, and selecting medical treatments (Newall, 2016; Petrova et al., 2017; Reyna et al., 2009). Numeracy has also been found to predict adaptive self-regulation and skilled metacognitive processing (e.g., thinking about your own thoughts and feelings, and more accurately evaluating the thoughts and feelings of others) as revealed in studies showing more strategic deliberation during risky decision making, more vivid encoding and personalization of practical and emotional context of decision problems, and more accurate self-assessment of knowledge, skills, and decision outcomes (e.g., overconfidence vulnerability; Cokely & Kelly, 2009; Ghazal et al., 2014; Ybarra, 2018). In turn, these factors often work in concert with basic probabilistic math knowledge, which tends to promote more precise and efficient interpretation and evaluation of technical information about risks and trade-offs (Cokely et al., 2012, 2018; Cokely & Kelley, 2009; Peters, 2012; Peters et al., 2006; Petrova et al., 2017).

The constellation of skills associated with numeracy and risk literacy generally tends to facilitate the acquisition of valuable, accurate, and relevant domain-specific knowledge, both in more common situations and given rapidly evolving high-stakes issues like pandemic responses (Downs et al., 2008; Pennycook et al., 2015, 2020; Pennycook & Rand, 2018; Sarathchandra et al., 2018). For example, numerate people are more knowledgeable about specific financial products (e.g., loans, credit cards), they tend to be more educated, they have more knowledge about specific scientific and legal facts, and they often have a more nuanced understanding of common health and lifestyle risks (Garcia-Retamero & Cokely, 2017). Numerate individuals also tend to have more accurate knowledge about local and national social and cultural norms (e.g., what

behavior is socially appropriate at work vs. leisure settings), and may be better able to estimate the prevalence of many kinds of cognitive and social biases in other people (e.g., Ybarra, 2018). Although there is relatively less research on the acquisition of valuable domain-specific and domain-general knowledge, evidence suggests that more numerate people may be better at evaluating the quality of information and risk communications, and numerate people may also tend to more accurately evaluate the potential payoff of different types of deliberation and problem solving activities, so they tend to more adaptively invest their limited cognitive resources and select strategies in such a way as to deliberately and deeply encode relevant information in highly contextualized and durable representations, which tend to be much more resilient against the effects of forgetting (e.g., Cokely et al., 2006, 2009, 2018; Feltz & Feltz, 2019; Mahmoud-Elhaj et al., 2020).

Numeracy and Motivated Reasoning

Despite the considerable evidence showing that numeracy tends to be one of the strongest predictors of skilled decision making and risk literacy, some studies suggest that within some controversial or politically-charged domains numeracy may potentially be associated with non-normative judgments and biases (Drummond & Fischhoff, 2017; Kahan et al., 2011, 2012). For example, a study by Kahan et al. (2012) suggested that numeracy had a very small, yet significant interaction with worldviews such that highly numerate people with specific cultural worldviews may express greater risk attitude polarization, consistent with a motivated reasoning hypothesis. In the study, participants were categorized into four groups (i.e., two worldview groups with opposing views – hierarchical individualists and communitarian egalitarians – with low or high cognitive skill) and their perception of global warming risk was examined. The results indicated that the gap between the two cultural worldview groups in global warming risk perception did not

decrease, but instead the relationship between numeracy and worldview appeared to interact. That is, numerate individuals with extreme worldviews showed more, not less polarization in risk attitudes. Of note, while the results are suggestive, one potential confound that has received relatively little attention concerns the extent to which the observed differences in risk attitudes do indeed reflected fundamental differences in non-normative judgments (e.g., selecting a more expensive fixed rate loan because you underestimate the benefits of the available adjustable rate loan), as compared to differences in risk attitudes that may follow from established well-ordered risk preferences (e.g., deliberately selecting the more expensive loan because you value the certainly of a fixed cost).

Other research using related approaches also suggests that numerate individuals may have more polarized risk attitudes, which could theoretically follow from more skilled use of self-serving (motivated) reasoning in accord with one's worldviews (Kahan et al., 2017). For example, in a study by Kahan et al. (2017), participants were provided with a piece of statistical information (i.e., a contingency table) with results from fictional studies on two different issues (i.e., skin rash cream and gun control). Participants were then asked to select a conclusion that they believe the given evidence supports. The results reported that highly numerate individuals tended to give more polarized answers when they were given information about gun control (a more polarizing topic) as compared to skin rash cream (a less polarizing topic). The results further suggested that less numerate participants were less likely to demonstrate this polarizing pattern. Together, this might reflect a pattern of logically inconsistent reasoning (e.g., applying different standards to different topics). Alternatively, if people who care about gun control were also more likely to know more about research on gun control policies and studies (compared to skin care products), then it becomes harder to simply interpret differences in responses as non-normative biases. That is, it

seems reasonable that people who know more or less about a topic could logically come to different judgements about the relative risks or values of different policies. In this case, differences in knowledge could have had even stronger influences on judgments because the evidence depicted presented relatively weak, and only marginally significant results from a fictional study (e.g., the outcome data was significant for one tail but not two tailed test, which would be required if you truly had no prior hypothesis about an outcome). Our ability to accurately evaluate the logic or biases of different people becomes much more complicated in the presence of such a strong potential confound.

Taken together, while the majority of available research on numeracy suggests that numeracy skills tend to promote more resilient, skilled and accurate decision making and knowledge acquisition, some research suggests that these relations may not necessarily hold for some climate-related judgments that appear to be affected by small but significant interactions between numeracy, worldviews, beliefs and risk attitudes. Theoretically, researchers suggest that these findings of potentially non-normative biases may indicate that numerate individuals generally tend to use their cognitive skills in the climate change domain in a self-serving manner, such that they may selectively search for, encode, and interpret available evidence in ways that support or protect a viewpoint that is most consistent with their cultural worldview. Whether or not the effects actually represent non-normative biases, the evidence indicates that in some situations there may be a surprising relationship between numeracy, worldviews, beliefs and attitudes. Nevertheless, all available studies suggesting these potential biases have neglected potential confounds related to potentially influential differences in knowledge, which could be confounded with reported differences or interactions with worldviews, beliefs, and attitudes (Table 1).

Table 1

Classes of Variables in Previous Studies and Current Study

	Variables				
Authors	**Numeracy (Risk Literacy)**	**Value**	**Knowledge**	**Belief**	**Downstream consequence**
Kahan et al., 2017	✔	✔			✔
Kahan et al., 2012	✔	✔			✔
van der Linden et al., 2015		✔	✔	✔	✔
Ding et al., 2011		✔	✔	✔	✔
Kahan et al., 2011		✔	✔	✔	
Lewandowsky et al., 2013		✔	✔	✔	
Drummond & Fischhoff, 2017		✔	✔	✔	
van der Linden et al., 2012		✔	✔		✔
Kobayashi, 2018			✔	✔	

Note. The table presents previous research that studied the climate change domain, and that were cited in the current investigation. Values include cultural worldview or ideology. Downstream consequences include attitude or behavioral intentions about climate change risks.

Current Study

Despite a growing body of evidence investigating the various interrelations among numeracy skills, knowledge, values, beliefs, and attitudes, there is a gap in the current literature. To date there do not appear to be any publicly available scientific studies reporting integrated tests of the interrelations among numeracy, cultural worldview orientations, climate science knowledge, climate change beliefs, and risk attitude. Given this and other gaps in the current literature, one primary aim of the current set of studies was to provide the first integrated test of the robustness of the relations between numeracy, knowledge, worldviews, and downstream beliefs and attitudes, conducting a direct test of the extent to which differences in beliefs and attitudes may generally be associated with protective versus polarizing influences of skills and knowledge. Specifically, Study 1 assessed and tested a structural cognitive model of the interplay of the primary variables (i.e., numeracy, worldview, climate knowledge and beliefs, and risk attitudes) using a

probabilistically representative sample of the U.S. adult population. In Study 2, I replicated and extended the assessment and test of the cognitive model using a convenience sample of diverse adult residents in the United States, in order to provide an out-of-sample cross-validation test of the integrated model, and in order to more precisely address emerging concerns about measurement of climate change risk perceptions without assessing differences in general risk perceptions (e.g., how risky is climate change compared to other risks in general).

Chapter 2: Study 1

In order to provide a robust test of numeracy's relationship to accurate or polarized views on climate change, this study uses a probabilistically representative sample to construct the first model that integrates numeracy, expert consensus, belief about anthropogenic global warming, and global warming risk perception.

Participants

The representative sample of the U.S. population was collected in spring of 2016, using a probability-based sampling panel (KnowledgePanel® from GfK). A total of 305 cases were reported for the analysis. Table 2 presents demographic characteristics of the participants.

Table 2

Demographics

Categories	Current Sample (2016)	National Census Estimate (2016)
Gender		
Male	53.4%	49.2%
Female	46.6%	50.8%
Age		
18-34	27.5%	27.4%
35–44	19.3%	12.7%
45-64	39.3%	26.2%
65+	13.8%	14.5%
Education		
Less than High School	11.8%	13%
High School	31.1%	27.5%
Some College	26.6%	21%
Bachelor and beyond	30.5%	30.3%

Note. Information was obtained from the estimate of US Census Bureau (2010 – 2016)

Measure

Statistical Numeracy

The Berlin Numeracy Test and a three-item scale created by Schwartz et al. (1997) were used to assess numeracy and risk literacy (Cokely et al., 2012). Using the two tests together increases sensitivity of the measurement, allowing for a wider range of skill assessment.

Expert Consensus Knowledge

Knowledge in expert consensus about anthropogenic global warming was assessed by asking the extent to which participants agreed with the statement that most experts believe that greenhouse gases cause increases in global temperature (i.e., *According to most experts, are greenhouse gases, such as those resulting from the combustion of coal, oil, natural gas, and other materials, causing average global temperatures to rise?*). The scale ranged from 0 (Strongly disagree) to 10 (Strongly agree).

Belief in Anthropogenic Global Warming (AGW)

Belief in anthropogenic global warming (AGW) was measured with an item asking the degree to which participants agreed with the statement that they personally believe greenhouse gases cause an increase in global temperature (i.e., *In your view, are greenhouse gases, such as those resulting from the combustion of coal, oil, natural gas, and other materials, causing average global temperatures to rise?*). The scale ranged from 0 (Strongly disagree) to 10 (Strongly agree).

Global Warming Risk Perception

Perceived risk about global warming was measured with one item: *How much risk do you think global warming poses for people and the environment?* The scale ranged from 0 (No Risk) to 10 (Extreme Risk).

Cultural Theory

The 12-item scale from previous studies (e.g., Jenkins-Smith & Smith, 1994; Jones, 2011; Ripberger et al., 2011, 2012; Wildavsky & Dake, 1990) was used to measure four indices of cultural theory: individualism (Cronbach's α = .54), egalitarianism (Cronbach's α = .76), hierarchy (Cronbach's α = .67), and fatalism (Cronbach's α = .58; See Table S1). Each index was composed of three statements. Respondents rated the degree to which they agree with each statement, from a scale of 1 (Strongly disagree) to 6 (Strongly agree).[1] The mean rating for the three statements was used as a score for each cultural theory index.

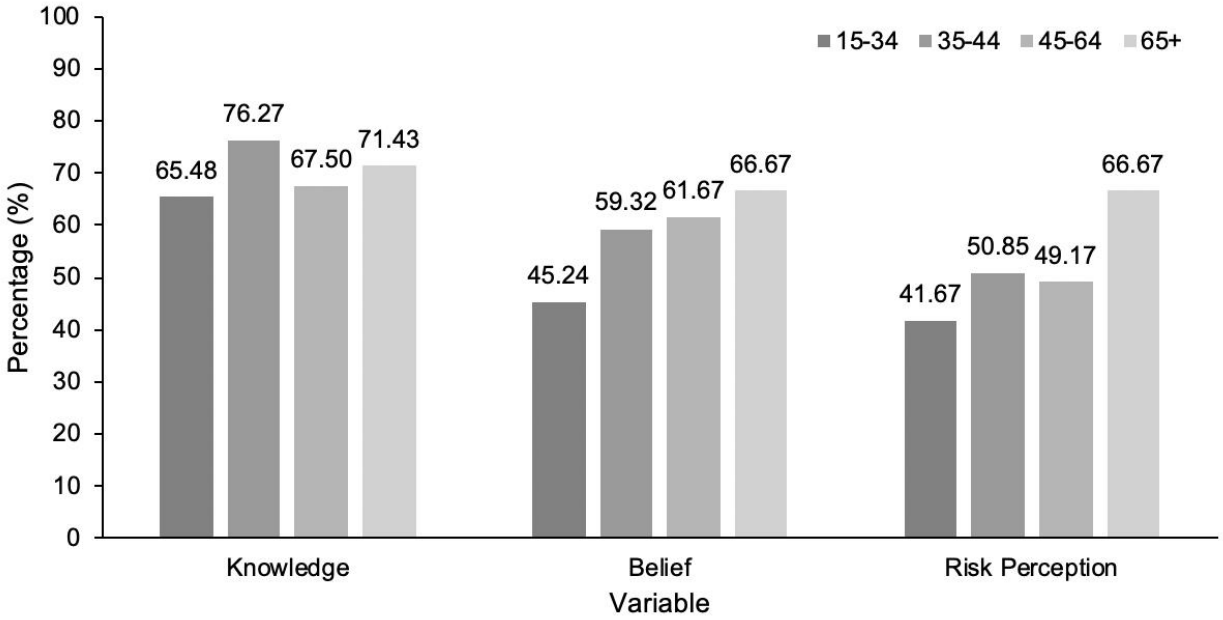
[1] One of the items for fatalism had a negative correlation with the other two, so the item was excluded. The reported Cronbach's α is after the exclusion.

Study 1: Analysis and Discussion

Eighty-four percent of participants agreed that there is a consensus among experts about anthropogenic global warming (i.e., answered 6 or more out of 10; M = 6.75, SD = 2.55). Furthermore, 61% of respondents indicated that they believe in anthropogenic global warming (M = 6.01, SD = 2.87). Together, this indicates that a majority of respondents may already have beliefs consistent with those of experts. Figure 1 presents the proportion of individuals that agree with the existence of expert consensus, believe in anthropogenic global warming, and have above-average global warming risk perceptions by age group. Though statistical numeracy was significantly correlated with knowledge in expert consensus (r = .16, p < .001; see Table 3), numeracy was not significantly correlated with belief in anthropogenic global warming or risk perceptions about global warming. These findings are consistent with previous research on the relationship between cognitive sophistication (e.g., numeracy) and attitudes about COVID-19 risks (Pennycook et al., 2020). Further, 50% of respondents displayed higher risk perceptions about global warming (M = 6.15, SD = 2.88).

Figure 1

Knowledge, Belief, and Risk Perception



Note. The plot represents the percentage of respondents that (i) agreed with the existence of expert consensus knowledge, (ii) personally believe in anthropogenic global warming, (iii) indicated above-average global warming risk perception, by age group.

An integrated model was constructed based on findings from previous studies. Specifically, previous evidence indicates that numeracy tends to be related to the acquisition of accurate knowledge, which in turn predicts beliefs and attitudes about risks (e.g., global warming; Cokely et al., 2018; Hornsey et al., 2016; Lewandowsky et al., 2013; van der Linden et al., 2015b, 2015c, 2017, 2019) [2]. As such, a structural equation model that integrates numeracy, knowledge, belief, and risk perception was constructed using the lavaan package in R version 3.5.2 (see Figure 2). Four cultural worldviews and demographics (i.e., age, gender) were included as covariates. Indirect effects were estimated using a bootstrapping method with 5,000 bootstrap samples (see Table 4). The model had a good fit: $\chi 2(2) = .56$, $p = .76$, CFI = 1.00, TLI = 1.00, SRMR = .00, RMSEA = .00 with 90% C.I (0.00-0.08).

[2] Interaction effects were tested but were not robust in the presence of main effects.

Table 3

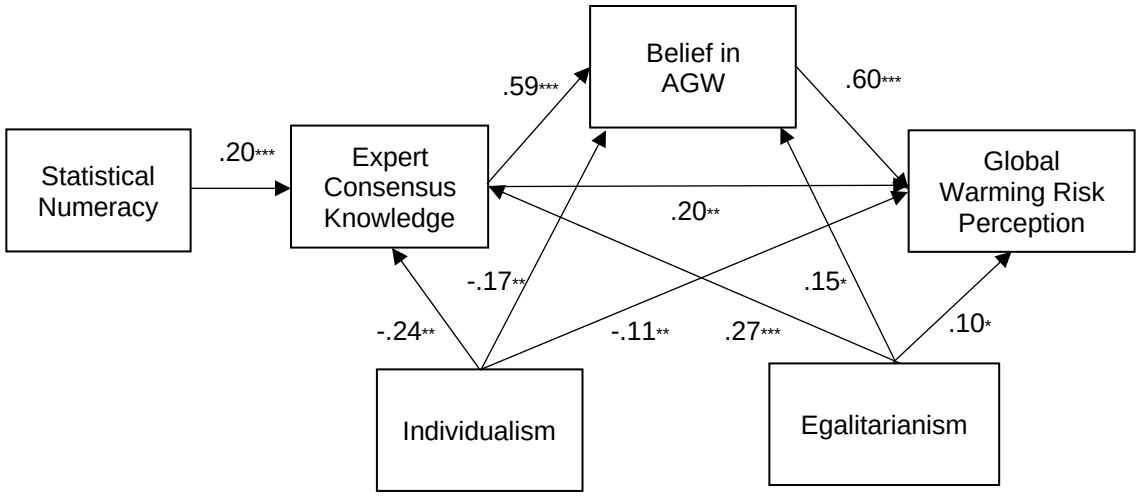
Descriptive Statistics and Correlation

	Variable	*M*	*SD*	1	2	3	4	5	6	7
1.	Perceived Risk	6.15	2.88	—						
2.	Belief in AGW	6.01	2.87	.80**	—					
3.	Expert Consensus Knowledge	6.75	2.55	.66**	.68**	—				
4.	Numeracy	2.70	2.02	.00	.04	.16**	—			
5.	Individualism	3.61	0.97	-.35**	-.33**	-.26**	.02	—		
6.	Egalitarianism	3.41	1.21	.39**	.39**	.28**	-.14*	-.17**	—	
7.	Hierarchy	3.33	1.05	.01	-.02	-.06	-.17**	.32**	.13*	—
8.	Fatalism	2.93	1.11	.14*	.17*	.06	-.15*	.17*	.31**	.27**

Note. *$p < .05$, **$p < .01$

Figure 2

An Integrated Model of Numeracy, Knowledge, Belief, and Risk Perception



Note. Reported are standardized coefficients after adjusting for age and gender. The representation does not include paths from hierarchy and fatalism, which were as follows: Hierarchy → Knowledge ($\beta = .01$, $p = .91$), Hierarchy → Belief ($\beta = .01$, $p = .94$), Hierarchy → Risk Perception ($\beta = .07$, $p = .09$), Fatalism → Knowledge ($\beta = .04$, $p = .61$), Fatalism → Belief ($\beta = .12$, $p < .05$), Fatalism → Risk Perception ($\beta = .05$, p = .69). *$p < .05$, **$p < .01$, ***$p < .001$

Table 4

Indirect Effects (Standardized Coefficients) of Key Variables

Path	Estimate	SE	Bootstrapped 95% CI
Knowledge → Belief → Risk Perception	.36***	.06	.28 .53
Numeracy → Knowledge → Belief	.12**	.05	.08, .27
Numeracy → Knowledge → Risk Perception	.04*	.03	.02, .11
Numeracy → Knowledge → Belief → Risk Perception	.07*	.03	.04, .17

Note. Effects were estimated with 5,000 bootstrap samples. *$p < .05$, **$p < .01$, ***$p < .001$

As seen in Figure 2, the model indicated that expert consensus knowledge was the strongest predictor of belief in anthropogenic global warming (AGW; $\beta = .59$, $p < .001$). Independent of belief, knowledge of expert consensus also had a direct effect on global warming risk perception ($\beta = .20$, $p < .001$). Numeracy further predicted expert consensus knowledge, independent of cultural worldviews and demographic variables ($\beta = .20$, $p < .001$). As seen in Table 4, numeracy had a significant indirect effect on both (i) belief in anthropogenic global warming and (ii) risk perceptions, mediated by knowledge.

How Powerful is Knowledge?

Knowledge and Climate Change Beliefs

To better understand the predictive power of knowledge on belief in anthropogenic global warming, a binary logistic regression model was constructed (see Table 5). The dependent variable was dichotomized to represent whether an individual believed in anthropogenic global warming or not (i.e., a rating between 0 and 5 was recoded as Disagree or neutral (0); a rating between 6 and 10 was recoded as Agree (1)). Predictor variables included expert consensus knowledge, cultural worldviews, and demographic variables. For interpretability, expert consensus knowledge was also dichotomized to represent whether one agreed with the existence of expert consensus

about anthropogenic global warming or not (Rating 0 to 5 = Disagree or neutral (0); Rating 6 to 10 = Agree (1)).

Table 5

Binary Logistic Regression on Climate Change Beliefs

Variable	B	SE	Wald	OR	95% CI for OR
Knowledge	2.78***	0.37	57.54	16.08	7.85, 32.96
Individualism	-0.28	0.18	2.41	0.76	0.53, 1.08
Egalitarianism	0.36**	0.14	7.01	1.43	1.10, 1.87
Hierarchy	0.03	0.16	0.04	1.03	0.76, 1.41
Fatalism	0.23	0.15	2.44	1.26	0.94, 1.69
Age	0.03**	0.01	8.54	1.03	1.01, 1.05
Gender	0.31	0.31	1.01	1.36	0.75, 2.47

Note. The dependent variable was belief in anthropogenic global warming dichotomized to represent whether one agrees or does not agree (0-5 vs. 6-10). Expert consensus knowledge was dichotomized to represent whether one agrees or does not agree with the existence of expert consensus (0-5 vs. 6-10). $*p < .05$, $**p < .01$, $***p < .001$

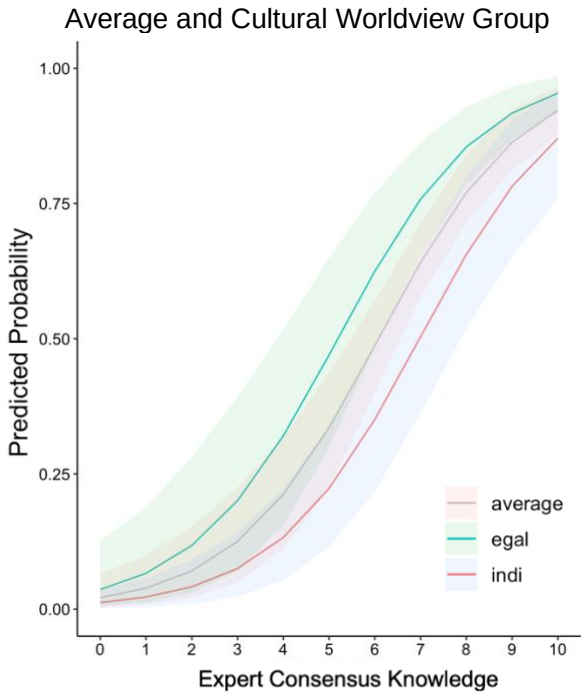
As seen in Table 5, results indicated that expert consensus knowledge was indeed a significant predictor. The odds ratio for knowledge was 16.08 with 95% CI [7.85, 32.96], indicating that the odds of agreeing with anthropogenic global warming tend to be roughly 16 times larger among individuals that agree with the existence of expert consensus, as compared to those who do not.

To better illustrate the relationship between expert consensus knowledge on global warming beliefs, the predicted probability of belief in anthropogenic global warming was plotted with respect to scores on expert consensus knowledge. This is presented for three different cultural worldview groups: the national average, individualist, and egalitarians (see Figure 3). A binary logistic regression model was used, where expert consensus knowledge and the four cultural worldviews were predictor variables. Given the diverse groups, the criteria assumed that individualist (egalitarian) score at 1 standard deviation above the mean, and egalitarianism

(individualism) score at 1 standard deviation below the mean. The other two variables were held at their mean. The predictions were generated using a bootstrap with 1,000 simulations.

Figure 3

Knowledge and Climate Change Beliefs



Note. Results depict the predicted probability for belief in anthropogenic global warming at different levels of knowledge and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) at least 1 standard deviation above the mean, while also scoring at least 1 standard deviation below the mean on egalitarianism (individualism). All other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

The results indicate that for all three groups, as agreement with the existence of expert consensus knowledge increases, the probability of agreement with anthropogenic climate change also increases. This is consistent with suggestions from previous studies that emphasized the role of expert consensus knowledge in shaping beliefs on climate change (Lewandowsky et al., 2013; van der Linden et al., 2015).

Knowledge and Global Warming Risk Perception

Following previous analyses, a binary logistic regression was conducted to better understand the predictive power of expert consensus knowledge on global warming risk perception. Global warming risk perception was recoded as a binary outcome variable to represent whether an individual displayed above average global warming risk perception (Rating 0 to 6 = Below mean (0); Rating 7 to 10 = Above mean (1)). Predictor variables were expert consensus knowledge, cultural worldviews, and demographic variables.

Table 6

Binary Logistic Regression on Global Warming Risk Perception

Variable	B	SE	Wald	OR	95% CI for OR
Knowledge	2.30***	9.93	39.37	9.93	4.85, 20.35
Individualism	-0.56**	0.57	9.69	0.57	0.41, 0.81
Egalitarianism	0.51***	1.66	14.28	1.66	1.28, 2.17
Hierarchy	0.08	1.08	0.27	1.08	0.80, 1.47
Fatalism	0.02	1.02	0.01	1.02	0.76, 1.35
Age	0.03**	1.03	8.56	1.03	1.01, 1.05
Gender	-0.11	0.89	0.16	0.89	0.51, 1.57

Note. Dependent variable was global warming risk perception dichotomized to represent whether one has risk perception above the mean of the current sample (0-6 vs. 7-10). Expert consensus knowledge was dichotomized to represent whether one agrees or does not agree with the existence of expert consensus (0-5 vs 6-10). $*p < .05$, $**p < .01$, $***p < .001$

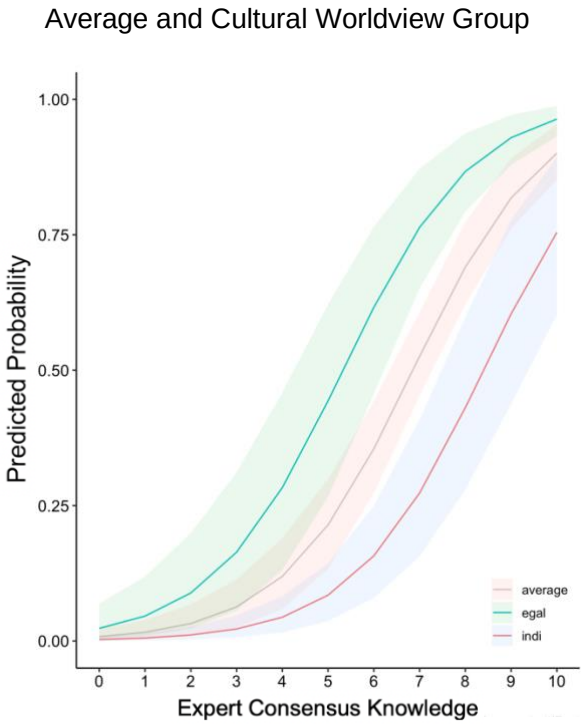
As seen in Table 6, the results suggest that expert consensus knowledge was a significant predictor. The odds ratio for knowledge was 9.93 with 95% CI [4.85, 20.35], suggesting that the odds of having global warming risk perception above average tends to be almost 10 times larger among individuals that agree with the existence of expert consensus, as compared to those who do not.

Again, predicted probabilities of having above-average risk perception for global warming at each score of expert consensus knowledge were simulated for three different groups: the national average, individualist, and egalitarians (see Figure 4). A binary logistic regression was used for prediction. Global warming risk perception was the outcome variable, after being dichotomized to

represent whether an individual had above-average global warming risk perception. Expert consensus knowledge and the four cultural worldviews were used as predictor variables. The predictions were generated using a bootstrap with 1,000 simulations. The individualist (egalitarian) group was assumed to have individualism (egalitarianism) at 1 standard deviation above the mean, and egalitarianism (individualism) at 1 standard deviation below the mean, while the other two variables were held at their mean.

Figure 4

Knowledge and Global Warming Risk Perception



Note. Results depict the predicted probability for having above-average global warming risk perception at different levels of knowledge and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) ratings 1 standard deviation above mean, and egalitarianism (individualism) ratings 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

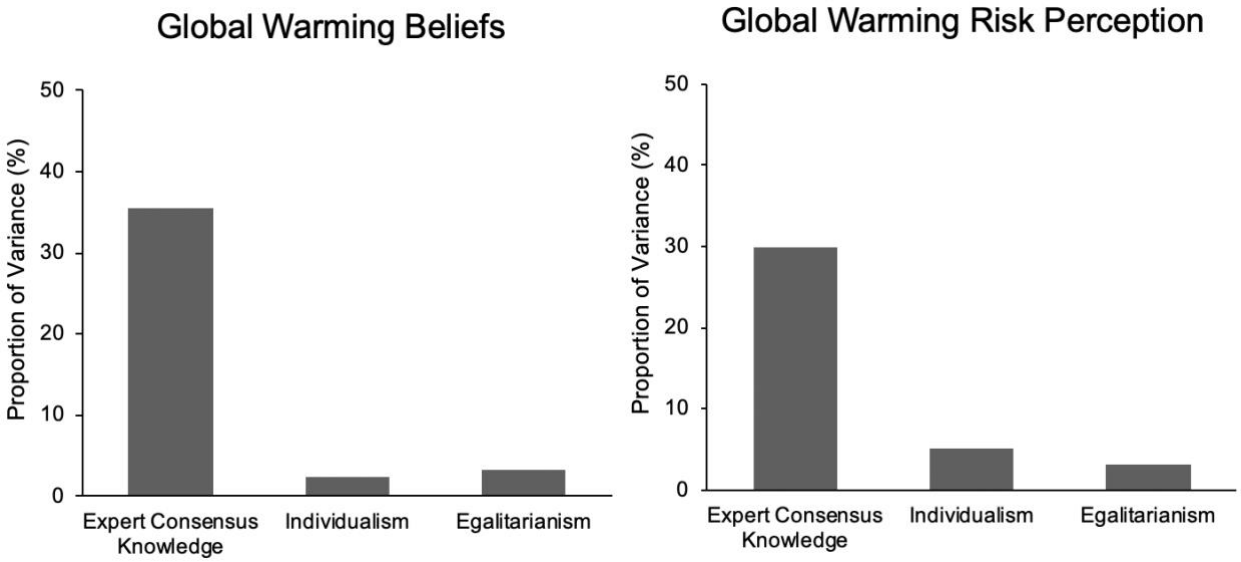
The results indicate that as agreement with existence of expert consensus knowledge increases, the probability to have increased global warming risk perception also increases. Of note,

the mean differences in trend between the three groups was also greater, as compared to the previous analysis which predicted belief in anthropogenic global warming.

To illustrate the relative contribution of knowledge and the cultural indices on beliefs and risk perception about global warming, the proportion of variance explained by each of the variables was calculated from two linear regression models predicting global warming beliefs and risk perception, respectively, with expert consensus knowledge and four cultural worldview indices as predictor variables (see Figure 5).

Figure 5

Comparison of Proportion of Variance by Knowledge and Main Cultural Worldview Indices



Note. Proportion of variance in each of the outcome variables (e.g., global warming beliefs and risk perception) explained by expert consensus knowledge and cultural worldview indices are presented. Multiple linear regression models with expert consensus knowledge and cultural worldview indices as predictor variables were used. In both cases with belief and risk perception as an outcome variable, proportion of variance explained by knowledge exceeded that of main cultural worldview indices.

In both cases, expert consensus knowledge explained a larger proportion of variance than individualism or egalitarianism. This is consistent with the notion of knowledge is power suggested by Skilled Decision Theory (Cokely et al., 2018).

Is Numeracy a Robust Predictor?

Numeracy and Expert Consensus Knowledge

In the integrated model, numeracy predicted expert consensus knowledge, independent of cultural worldview indices (β = .20, p < .001). To better understand the relationship between numeracy and expert consensus knowledge, a binary logistic regression was constructed (see Table 7). Expert consensus knowledge was used as an outcome variable after being recoded into a binary variable to represent whether one agrees with the existence of expert consensus in anthropogenic global warming or not (0-5 = Disagree or neutral (0); 6-10 = Agree (1)). In this model, statistical numeracy was used as a predictor variable along with cultural worldviews and demographic variables.

Table 7

Binary Logistic Regression on Expert Consensus Knowledge

Variable	B	SE	Wald	OR	95% CI for OR
Numeracy	0.30***	0.08	14.11	1.35	1.16, 1.58
Individualism	-0.45**	0.16	8.17	0.64	0.47, 0.87
Egalitarianism	0.51***	0.14	13.62	1.67	1.27, 2.20
Hierarchy	0.09	0.15	0.42	1.10	0.83, 1.46
Fatalism	0.02	0.14	0.02	1.02	0.78, 1.33
Age	0.00	0.01	0.19	1.00	0.99, 1.02
Gender	-0.28	0.28	0.95	0.76	0.44, 1.32

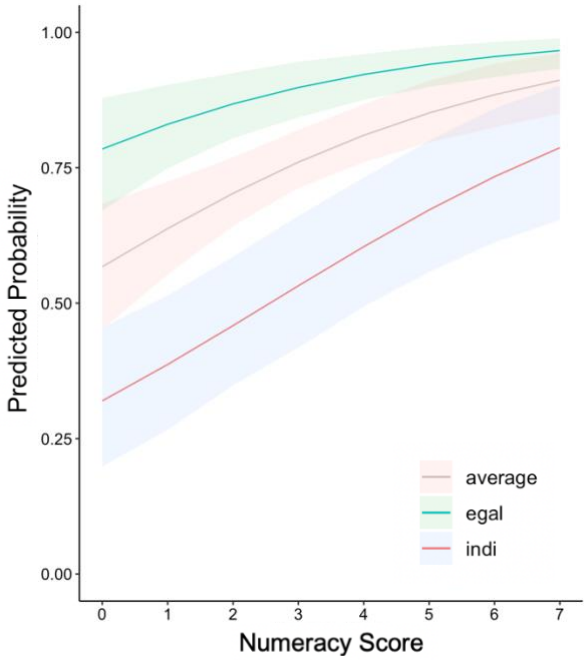
Note. Dependent variable was expert consensus knowledge dichotomized to represent whether one agree or not agree with existence of expert consensus (0-5 vs. 6-10). *p < .05, **p < .01, ***p < .001

As seen in Table 7, results indicated that statistical numeracy was a significant predictor, with odds ratio of 1.35 with 95% CI [1.16, 1.58]. Accounting for the continuous nature of the numeracy scale (scores between 0 and 7), this indicates that individuals with the highest numeracy score are approximately 8 times more likely to have expert consensus knowledge, as compared to that of individuals with the lowest numeracy score.

The predicted probabilities for knowledge of expert consensus of anthropogenic global warming across different levels of numeracy and cultural worldview groups were generated (see Figure 6). Following the standard method, a bootstrapped binary logistic regression model was used for prediction, where the outcome variable was expert consensus knowledge after being dichotomized to represent whether one agrees with the existence of expert consensus in anthropogenic global warming or not (0-5 = Disagree or neutral (0); 6-10 = Agree (1)).

Figure 6

Numeracy and Expert Consensus Knowledge



Note. Results depict the predicted probability of indicating that there is expert consensus about anthropogenic global warming. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

The results illustrate that when numeracy is high, the predicted probability for agreement with expert consensus tends to be similar, even among different cultural worldview groups.

Consistent with Skilled Decision Theory, this implies that numeracy may in fact predict reduced biases in knowledge, despite different cultural worldviews.

Numeracy and Climate Change Beliefs

Another binary logistic regression predicting belief in anthropogenic global warming was constructed with the same set of predictor variables: numeracy, cultural worldviews, and demographics (Table 8).

Table 8

Binary Logistic Regression on Climate Change Beliefs

Variable	B	SE	Wald	OR	95% CI for OR
Numeracy	0.24***	0.07	11.67	1.27	1.11, 1.46
Individualism	-0.45**	0.15	8.60	0.64	0.47, 0.86
Egalitarianism	0.54***	0.13	18.41	1.71	1.34, 2.19
Hierarchy	0.12	0.14	0.68	1.12	0.85, 1.48
Fatalism	0.20	0.13	2.36	1.22	0.95, 1.58
Age	0.02**	0.01	7.85	1.02	1.01, 1.04
Gender	0.19	0.27	0.48	1.20	0.72, 2.03

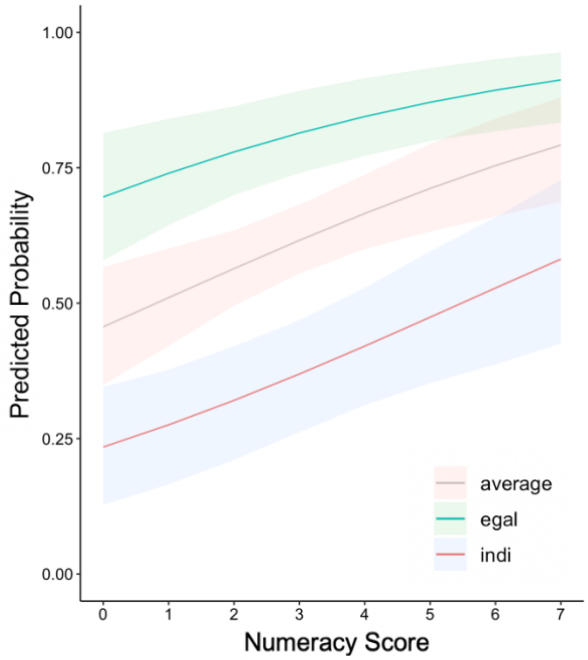
Note. Dependent variable was belief in anthropogenic global warming dichotomized to represent whether one agree or not agree with anthropogenic global warming (0-5 vs. 6-10). *$p < .05$, **$p < .01$, ***$p < .001$

As seen in Table 8, the odds ratio for numeracy was 1.27 with 95% CI [1.11, 1.46], indicating that individuals with the highest numeracy score are nearly 5 times more likely to agree with anthropogenic global warming, as compared to those with the lowest numeracy score.

Following from the previous analyses, predicted probabilities for belief in anthropogenic global warming (see Figure 7) were modeled with respect to numeracy scores. Again, a bootstrapped binary logistic regression model was used for prediction.

Figure 7

Numeracy and Climate Change Beliefs



Note. Results depict the predicted probability of believing in anthropogenic global warming at different levels of numeracy and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

The results illustrate that as numeracy increases, so does the probability of accurate beliefs both for egalitarians and individualists. Contrary to some previous suggestions, there is no evidence of numeracy causing polarizing beliefs in climate change (i.e., motivated reasoning). Accordingly, these findings are consistent with Skilled Decision Theory (Cokely et al., 2018).

Numeracy and Global Warming Risk Perception

Even though the results of the integrated model (Figure 2) indicated that the relationship between numeracy and global warming risk perception is fully mediated by expert consensus knowledge, the relationship between numeracy and risk perception were examined using a binary logistic regression model (see Table 9). The outcome variable of the model was whether one

displayed global warming risk perception above the mean, generated by dichotomizing the global warming risk perception variable (0-6 = below mean (0) vs. 7-10 = above mean (1)). The predictor variables were statistical numeracy, cultural worldviews, and demographic variables.

Table 9

Binary Logistic Regression on Global Warming Risk Perception

Variable	B	SE	Wald	OR	95% CI for OR
Numeracy	0.14*	0.07	4.18	1.15	1.01, 1.31
Individualism	-0.64***	0.16	15.83	0.53	0.39, 0.72
Egalitarianism	0.64***	0.13	24.68	1.89	1.47, 2.44
Hierarchy	0.11	0.14	0.58	1.12	0.84, 1.48
Fatalism	0.01	0.13	0.00	1.01	0.78, 1.31
Age	0.03**	0.01	8.52	1.03	1.01, 1.04
Gender	-0.18	0.26	0.48	0.83	0.50, 1.40

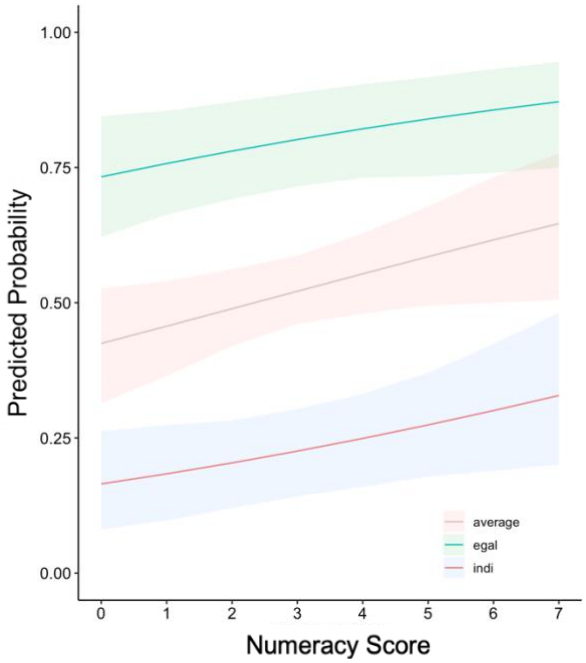
Note. Dependent variable was global warming risk perception dichotomized to represent whether one has risk perception above the mean of the current sample (0-6 vs. 7-10). *$p < .05$, **$p < .01$, ***$p < .001$

As shown in Table 9, numeracy was a statistically significant predictor of whether one shows above average global warming risk perception. The odds ratio of numeracy was 1.15 with 95% CI [1.01, 1.31]. When individuals with lowest versus highest numeracy scores are compared, the odds of having above average global warming risk perceptions were approximately 2.7 times larger among more numerate individuals.

To visualize the relationship with numeracy and global warming risk perception, predicted probabilities for above average global warming risk perception were generated with bootstrap simulation with 1,000 iterations, across a range of numeracy scores for three different worldview groups (Figure 8).

Figure 8

Numeracy and Global Warming Risk Perception



Note. Results depict the predicted probability of having above-average global warming risk perception at different levels of numeracy and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

As numeracy score increased, the probability to have above-average risk perception showed an increasing trend for all three worldview groups. However, this implies that there may be relatively constant differences in risk perceptions between individualists and egalitarians. Previous research may explain this as numeracy tends to have an indirect effect on risk perceptions via more general knowledge or beliefs, which were not included in the model (Ramasubramanian, 2020).

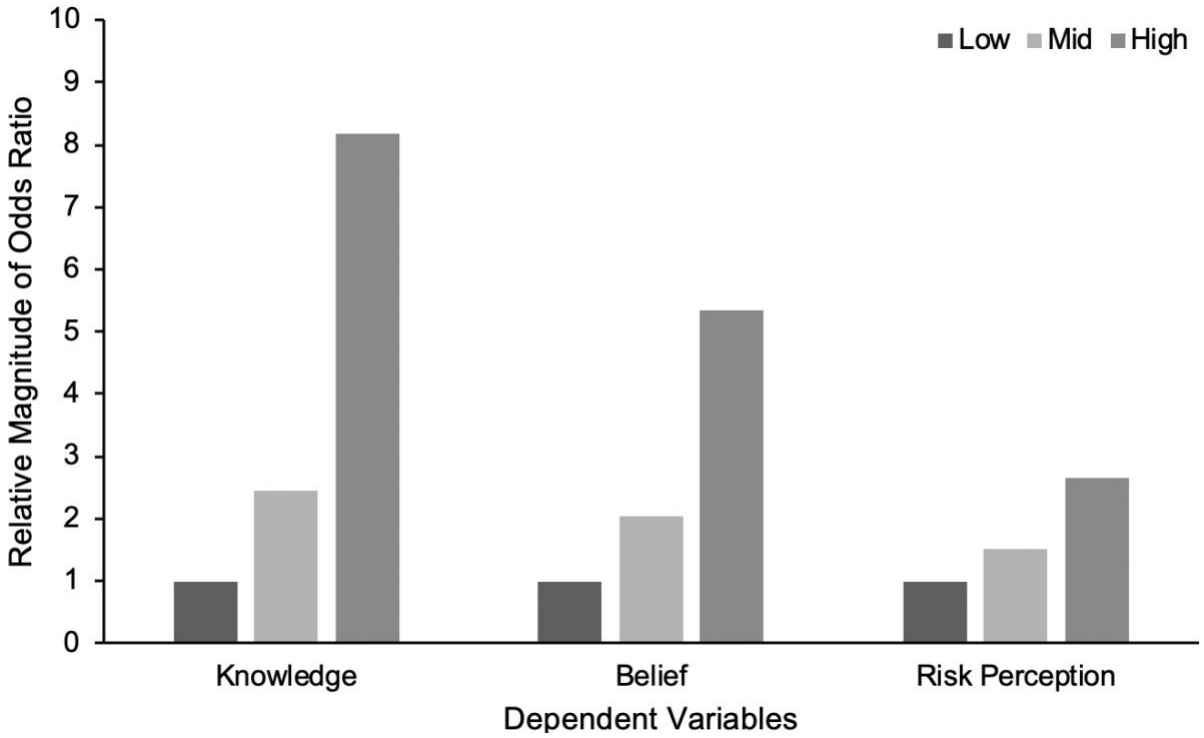
Study 1: Summary

In accord with recent studies, I found that a majority of people (61%) tend to already have accurate knowledge and beliefs about global warming. The first test of an integrated model that

includes numeracy, knowledge, belief, and risk perception was conducted using a probabilistically representative national sample. Here I document that numeracy directly predicted accurate knowledge, and numeracy had indirect effects on key outcomes such as belief and risk attitudes (i.e., downstream consequences), independent of cultural worldviews. The downstream benefits of numeracy are relatively robust and consistent (see Figure 9). Furthermore, knowledge was a powerful predictor of belief and risk perception, accounting for more than 10 times more variance in climate change beliefs as compared to each of the cultural worldview indices (e.g., individualism, egalitarianism).

Figure 9

Numeracy, Knowledge, Belief, and Risk Perception



Note. Each bar represents the relative magnitude of the odds ratio at three different scores of numeracy (i.e., low = 0, mid = 3, high = 7) for (i) having expert consensus knowledge, (ii) belief in anthropogenic global warming, and having above-average global warming risk perception. The results were based on three binary logistic regression models all of which had numeracy and cultural worldviews as predictor variables.

Interestingly, no evidence for polarization was observed. Although the integrated model indicated that numeracy had an indirect effect on risk perceptions via knowledge and beliefs, there was no direct relationship between numeracy and risk perception on a zero-order correlation. In fact, many of the studies that previously documented the polarizing role of numeracy focused only on risk perception. However, they also did not assess a potentially influential prior, namely, general risk perception or relative risk perception (i.e., how much worse is climate change compared to other risks such as nuclear power). In theory, as numerate individuals may acquire more knowledge on diverse risks, there may be a difference in general risk perception. Thus, Study 2 was designed to test whether assessing general risk perception can help explain a relationship between numeracy and domain-specific risk perception (i.e., global warming risk perception).

Chapter 3: Study 2

In Study 2, I introduced general risk perception as a new variable to the integrated model. A convenience sample of diverse adults in the United States was collected in 2020. Many previous studies that examined the relationship between numeracy and domain-specific risk perception have not assessed general risk perception, which may help estimate relative differences in risk perception (e.g., global warming risk perception as compared to risk perception about other diverse risks). Thus, a main goal of Study 2 was to test whether assessing relative risk perception can explain the relationship between numeracy and global warming risk perception. The same methods and analyses from Study 1 were conducted to replicate key findings, while also including measures for the new variable: general risk perception. The subsequent analyses included integrated models with general risk perception as a function of numeracy.

Participants

The data was collected via Amazon Mechanical Turk in 2020 April, during the early phases of the COVID19 pandemic in America. Out of 1,043 cases, 537 were used for the analysis after excluding the respondents who took too little time, did not pay attention to the survey (as assessed by attention checks), or completed less than 90% of the survey elements (see Table 10 for demographic characteristics).

Table 10

Demographics of Study 1 and Study 2 Sample

Categories	Study 1 (2016)	Study 2 (2020)
Gender		
Male	53.4%	43%
Female	46.6%	57%
Age		
18-34	27.5%	45%
35–44	19.3%	22.2%
45-64	39.3%	24.4%
65+	13.8%	8.2%
Education		
Less than High School	11.8%	0.1%
High School	31.1%	9.6%
Some College	26.6%	27.9%
Bachelor and beyond	30.5%	61.6%

Measure

All of the same measures from Study 1 were included in Study 2. This includes: (i) Statistical Numeracy, (ii) Expert Consensus Knowledge (iii) Belief in Anthropogenic Global

Warming (iv) Global Warming Risk Perceptions, and (v) Cultural Theory[3]. In this study, one additional facet was measured: Domain-general risk perception.

Domain-general Risk Perception

Domain-general risk perception items were assessed using the format developed by Kahan et al., (2017) "*How much risk do the following pose for human health, safety and prosperity?*". Questions used a scale from 0 (No Risk at All) to 7 (Extremely High Risk). The five risks included (i) motor vehicles, (ii) skiing, (iii) alcohol, (iv) nuclear power, and (v) vaccination, which were measured in study of Fischhoff et al. (1978). The mean of the five items with a linear conversion was conducted to match the scale of global warming risk perception, which ranged from 0 to 10. The Cronbach's α after the conversion was .69.

Study 2: Analysis and Discussion

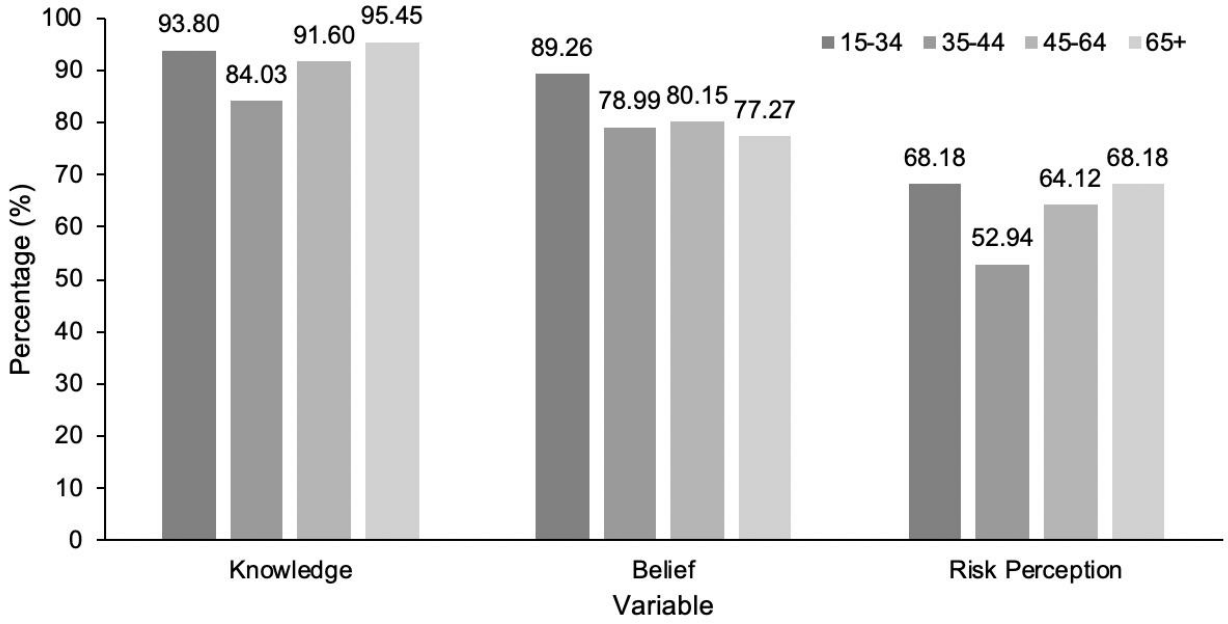
Over 90% of participants agreed that there is a consensus among experts about anthropogenic global warming (M = 8.17, SD = 1.90). Over 90% of respondents also indicated that they believe in anthropogenic global warming (M = 7.86, SD = 2.29), indicating that a majority of respondents may already have belief consistent with those of experts. The mean global warming risk perception rating was also higher than the scale midpoint (M = 7.80, SD = 2.16), indicating a skewed distribution, such that people on average tend to display higher risk perception about global warming. Figure 10 presents the proportion of individuals that agree with the existence of expert consensus, believe in anthropogenic global warming, and have above-average global warming risk perception by age group. As in Study 1, statistical numeracy was significantly correlated with knowledge in expert consensus (r = .13, p < .01; see Table 11). Numeracy was not significantly

[3] As in Study 1, only the two of three items for fatalism were used in analyses for consistency with Study 1.

correlated with belief in anthropogenic global warming or global warming risk perception, which is consistent with findings from Study 1.

Figure 10

Knowledge, Belief, and Risk Perception



Note. The plot represents the percentage of respondents that (i) agreed with existence of expert consensus knowledge, (ii) agreed with anthropogenic global warming, (iii) indicated above-average global warming risk perception, by age group. See Study 1 results in Figure 1.

Following the procedure from Study 1, an integrated model was tested, which was built based on assumptions of previous studies indicating that numeracy tends to predict accurate knowledge, which in turn often predicts downstream consequences such as beliefs and risk attitudes (see Figure 11). The model had good fit: $\chi_2(2) = 1.22$, $p = .54$, with CFI = 1.00, TLI = 1.00, SRMR = .004, RMSEA = .00 with 90% C.I (.00-.07).

Table 11

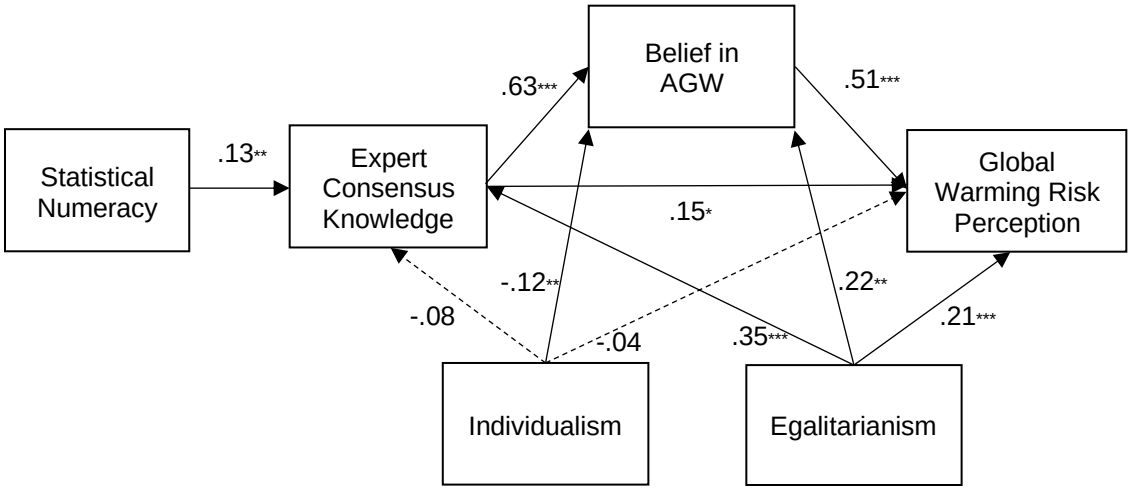
Correlation among Variables and Descriptive Statistics

	Variable	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	Perceived Risk	7.80	2.16	—												
2.	Belief in AGW	7.86	2.29	.74**	—											
3.	Expert Consensus Knowledge	8.17	1.90	.61**	.73**	—										
4.	Numeracy	2.88	1.92	-.02	.06	.13**	—									
5.	Individualism	3.60	1.14	-.21**	-.25**	-.23**	-.23**	—								
6.	Egalitarianism	4.28	1.28	.54**	.49**	.37**	-.11*	-.16**	—							
7.	Hierarchy	3.35	1.32	-.07	-.14**	-.19**	-.30**	.63**	-.03	—						
8.	Fatalism	3.60	1.15	.20**	.15**	.06	-.23**	.28**	.32**	.40**	—					
9.	Risk Perception General	6.09	1.71	.26**	.13**	.12**	-.30**	.20**	.25**	.27**	.28**	—				
10.	Skiing	7.44	2.17	.21**	.21**	.23**	.01	-.05	.17**	.00	.08	. 63**	—			
11.	Alcohol	5.83	2.90	.19**	.08	.08	-.24**	.12**	.21**	.17**	.15**	.75**	.42**	—		
12.	Nuclear Power	7.69	2.35	.37**	.22**	.22**	-.14**	-.03	.27**	.07	.09*	.69**	.36**	.39**	—	
13.	Vaccination	3.29	2.93	-.04	-.13**	-.16**	-.33**	.43**	.03	.41**	.35**	.59**	.09*	.33**	.14**	—
14.	Motor Vehicle	6.20	2.24	.20**	.13**	.10*	-.24**	.11**	.19**	.19**	.23**	.73**	.41**	.34**	.54**	.31**

Note. *$p < .05$, **$p < .01$

Figure 11

An Integrative Model of Numeracy, Knowledge, Belief, and Risk Perception



Note. Reported are standardized coefficients after adjusting for age and gender. The representation does not include paths from hierarchy and fatalism, which were as follows: Hierarchy → Knowledge (β = -.09, p = .09), Hierarchy → Belief (β = .04, p = .30), Hierarchy → Risk Perception (β = .04, p = .20), Fatalism → Knowledge (β = .04, p = .37), Fatalism → Belief (β = .04, p = .22), Fatalism → Risk Perception (β = .05, p = .19). *p < .05, **p < .01, ***p < .001

Table 12

Indirect Effects (Standardized Coefficients) of Key Variables

Path	Estimate	*SE*	Bootstrap 95% CI
Knowledge → Belief → Risk Perception	.32***	.05	.26, .46
Numeracy → Knowledge → Belief	.08**	.03	.03, .16
Numeracy → Knowledge → Risk Perception	.02	.01	.00, .06
Numeracy → Knowledge → Belief → Risk Perception	.04**	.02	.01, .08

Note. Effects were estimated with 5,000 bootstrap samples. *p < .05, **p < .01, ***p < .001

As seen in Figure 11, the model again suggested that expert consensus knowledge was the strongest predictor of belief in anthropogenic global warming (β = .63, p < .001), having direct and indirect effects on global warming risk perception, mediated by belief in anthropogenic global warming. Numeracy also predicted expert consensus knowledge (β = .13, p < .01) independent of

cultural worldviews and demographic variables (i.e., age, gender). Estimated indirect effects presented in Table 12 suggest that numeracy has significant indirect effects on belief via knowledge. The indirect effect to risk perception was significant when knowledge and belief were mediators.

How Powerful is Knowledge?

Knowledge and Climate Change Beliefs

A binary logistic regression model predicting whether one believes in anthropogenic global warming or not, was constructed to examine the predictive power of expert consensus knowledge (Table 13). The outcome variable was the dichotomized expert consensus knowledge variable (i.e., whether one agrees with existence of expert consensus or not), while cultural worldviews and demographics were predictor variables.

Table 13

Binary Logistic Regression on Belief in Anthropogenic Global Warming

Variable	B	SE	Wald	OR	95% CI for OR
Knowledge	3.89***	0.47	66.98	48.89	19.26, 124.11
Individualism	-0.51**	0.19	7.55	0.60	0.42, 0.86
Egalitarianism	0.67***	0.13	26.34	1.95	1.51, 2.52
Hierarchy	0.22	0.16	1.87	1.25	0.91, 1.73
Fatalism	0.09	0.16	0.31	1.09	0.80, 1.50
Age	-0.03**	0.01	8.50	0.97	0.95, 0.99
Gender	-0.61	0.33	3.51	0.54	0.29, 1.03

Note. Dependent variable was belief in anthropogenic global warming dichotomized to represent whether one agrees or does not agree with anthropogenic global warming (0-5 vs. 6-10). Expert consensus knowledge was dichotomized to represent whether one agrees or does not agree with the existence of expert consensus (0-5 vs. 6-10). *$p < .05$, **$p < .01$, ***$p < .001$

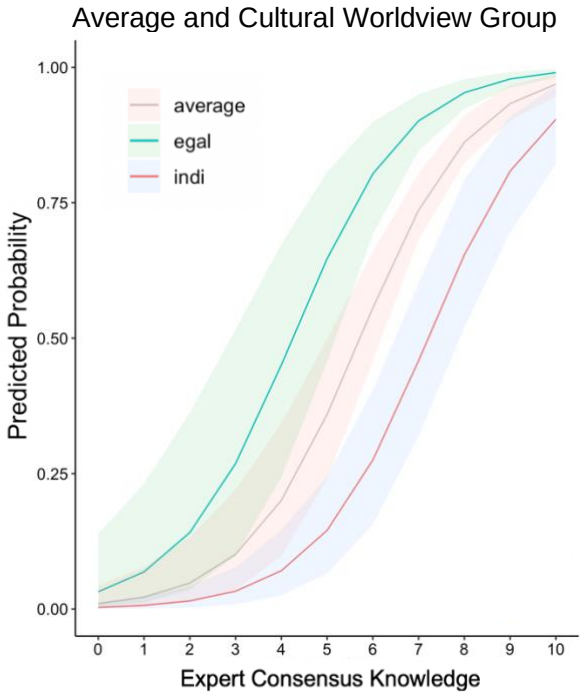
As seen in Table 13, expert consensus knowledge was a statistically significant predictor. The odds ratio for knowledge was 48.89 with 95% CI [19.26, 124.11]. The odds of having above average global warming risk perception tends to be nearly 50 times larger among individuals that

agree with the existence of expert consensus, than those who do not. Although there were relatively higher rates of belief in anthropogenic global warming as compared to Study 1, knowledge still emerged as a strong predictor of beliefs.

Predicted probabilities for belief in anthropogenic global warming for the three cultural groups were plotted across a range of scores on expert consensus knowledge (Figure 12). Using the same method as in Study 1, a bootstrapped binary logistic regression model was used. For the bootstrapped regression, the means and standard deviations from Study 1 (i.e., probabilistically representative sample) were used.

Figure 12

Knowledge and Climate Change Beliefs



Note. Results depict the predicted probability for belief in anthropogenic global warming at different levels of knowledge and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

Consistent with results from Study 1, as agreement with the existence of expert consensus increased, so did the predicted probability to believe in anthropogenic global warming. This is consistent with suggestions from previous studies emphasizing the role of knowledge in shaping beliefs about climate change (Lewandowsky et al., 2013; van der Linden et al., 2015c).

Knowledge and Global Warming Risk Perception

Next, a binary logistic regression model was tested for global warming risk perceptions. The variable was recoded so that responses between 0 and 7 were coded as Below average (0) and responses between 8 and 10 were coded as Above average (1) (Table 14).

Table 14

Binary Logistic Regression on Global Warming Risk Perception

Variable	B	SE	Wald	OR	95% CI for OR
Knowledge	3.23***	0.63	26.04	25.31	7.32, 87.57
Individualism	-0.46**	0.14	10.48	0.63	0.48, 0.84
Egalitarianism	0.69***	0.10	49.31	1.99	1.64, 2.42
Hierarchy	0.06	0.12	0.23	1.06	0.84, 1.34
Fatalism	0.20	0.12	2.90	1.22	0.97, 1.53
Age	0.00	0.01	0.01	1.00	0.99, 1.02
Gender	0.16	0.22	0.50	1.17	0.76, 1.79

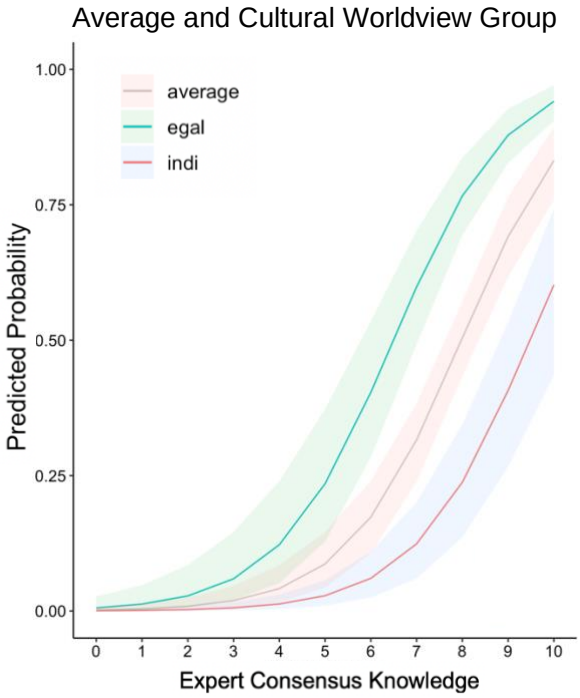
Note. Dependent variable was global warming risk perception dichotomized to represent whether one has risk perception above the mean of the current sample (0-7 vs. 8-10). Expert consensus knowledge was dichotomized to represent whether one agrees or does not agree with the existence of expert consensus (0-5 vs 6-10). *$p < .05$, **$p < .01$, ***$p < .001$

As shown in Table 14, the odds ratio for knowledge is 25.31 with 95% CI [7.32, 87.57]. This indicates that the odds of having above-average global warming risk perception tends to be 25 times higher among those with knowledge of expert consensus than those without.

The predicted probabilities for having above average global warming risk perception for three different cultural worldview groups were plotted across a range of scores for expert consensus knowledge. For the bootstrapped regression, the means and standard deviations from Study 1 (i.e., probabilistically representative sample) were used (Figure 13).

Figure 13

Knowledge and Global Warming Risk Perception

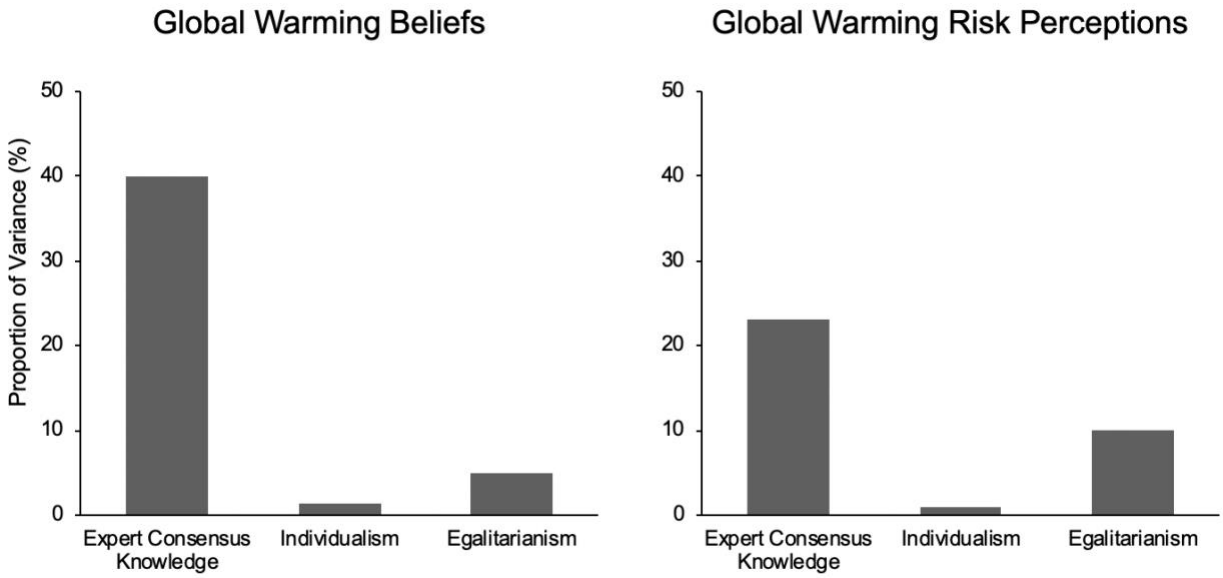


Note. Results depict the predicted probability for having above-average global warming risk perception at different levels of knowledge and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

Finally, the predictive power of knowledge and two main cultural worldview indices were compared using two linear regression models predicting (i) belief in anthropogenic global warming and (ii) global warming risk perception, with expert consensus and the four cultural worldview indices as predictor variables (Figure 14). The proportion of variance explained by knowledge and main cultural worldviews were graphed. Knowledge explained more variance than either cultural worldview indices, for both global warming beliefs and global warming risk perception.

Figure 14

Comparison of Proportion of Variance by Knowledge and Main Cultural Worldview Indices



Note. Proportion of variance in each of the outcome variables (e.g., global warming beliefs and risk perception) explained by expert consensus knowledge and cultural worldview indices are presented. Multiple linear regression models with expert consensus knowledge and cultural worldview indices as predictor variables were used. In both cases with belief and risk perception as an outcome variable, proportion of variance explained by knowledge exceeded that of main cultural worldview indices.

Is Numeracy a Robust Predictor?

Numeracy and Expert Consensus Knowledge

As in Study 1, statistical numeracy emerged as a predictor of expert consensus knowledge independent of cultural worldview and demographic variables. Expert consensus knowledge again fully mediated the relationship between numeracy and belief. As seen before numeracy had a significant indirect effect on belief in anthropogenic global warming and global warming risk perception.

Again, the relationship between numeracy and knowledge was examined using a binary logistic regression. The expert consensus knowledge variable was dichotomized to represent whether one agrees with existence of expert consensus or not (Table 15).

Table 15

Binary Logistic Regression on Expert Consensus Knowledge

Variable	B	SE	Wald	OR	95% CI for OR
Numeracy	0.18*	0.10	3.78	1.20	1.00, 1.45
Individualism	-0.13	0.18	0.58	0.88	0.62, 1.23
Egalitarianism	0.69***	0.14	23.71	2.00	1.51, 2.64
Hierarchy	-0.09	0.16	0.33	0.91	0.67, 1.25
Fatalism	0.01	0.18	0.00	1.01	0.71, 1.43
Age	0.01	0.01	0.16	1.01	0.98, 1.03
Gender	0.03	0.32	0.01	1.03	0.55, 1.93

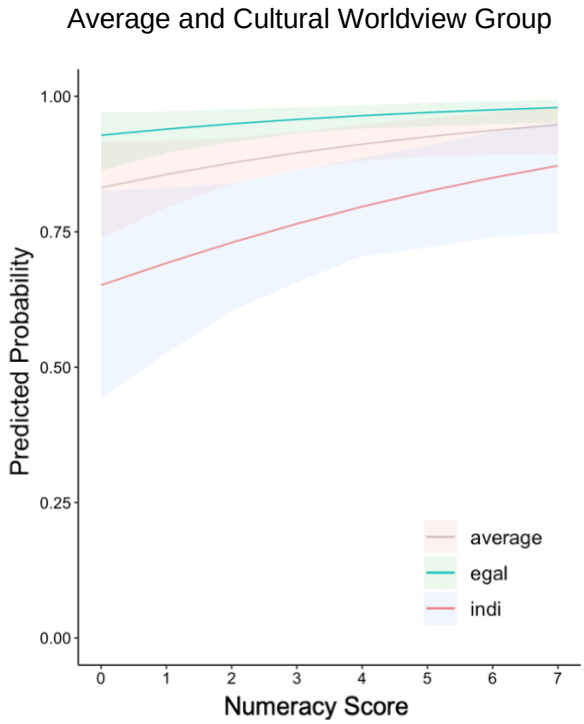
Note. Dependent variable was expert consensus knowledge dichotomized to represent whether one agrees or does not agree with existence of expert consensus (0-5 vs. 6-10). Median split was used to divide participants into two level of numeracy (low vs. high). *$p < .05$, **$p < .01$, ***$p < .001$

As seen in Table 15, the result indicated that odds ratio for numeracy was 1.20 with 95% CI [1.00, 1.45], suggesting that the odds of having knowledge of expert consensus is about 3.5 times higher for individuals with the highest numeracy score, as compared to those with the lowest numeracy score.

Again, the predicted probability for expert consensus knowledge was modeled using a binary regression model. For the bootstrapped regression, the means and standard deviations from Study 1 (i.e., probabilistically representative sample) were used (Figure 15).

Figure 15

Numeracy and Expert Consensus Knowledge



Note. Results depict the predicted probability of indicating that there is an expert consensus about anthropogenic global warming. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

The plot suggests evidence of a ceiling effect. This is consistent with the descriptive statistics that over 90% of respondents already had accurate knowledge, belief, and risk perceptions for global warming. This is true at an even a larger degree than what was seen in Study 1. Still, the predicted probability for the three groups displayed an increasing trend.

Numeracy and Climate Change Beliefs

Another binary logistic regression predicting belief in anthropogenic global warming was conducted (Table 16). Belief in anthropogenic global warming was used as an outcome variable after being dichotomized.

Table 16

Binary Logistic Regression on Belief in Anthropogenic Global Warming

Variable	B	SE	Wald	OR	95% CI for OR
Numeracy	0.14†	0.08	3.42	1.15	0.99, 1.34
Individualism	-0.43**	0.16	7.73	0.65	0.48, 0.88
Egalitarianism	0.80***	0.12	45.97	2.23	1.77, 2.81
Hierarchy	0.13	0.14	0.88	1.14	0.87, 1.48
Fatalism	0.07	0.14	0.25	1.07	0.81, 1.42
Age	-0.02*	0.01	4.96	0.98	0.96, 1.00
Gender	-0.45†	0.27	2.74	0.64	0.37, 1.09

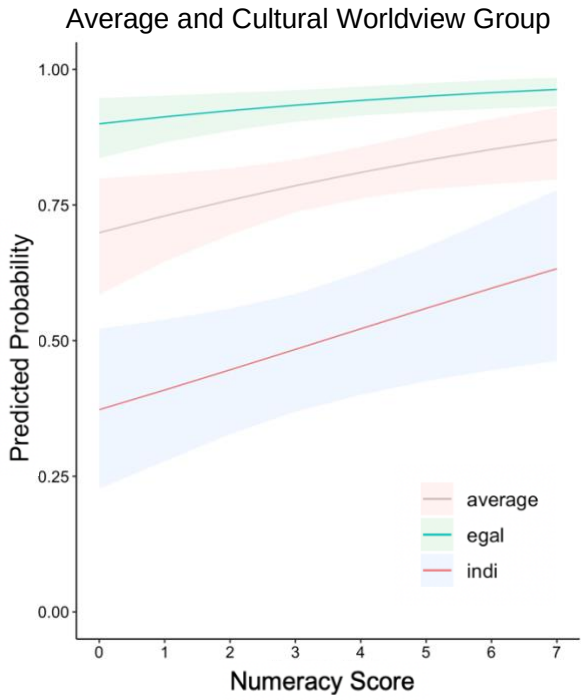
Note. The dependent variable was belief in anthropogenic global warming dichotomized to represent whether one agrees or does not agree with anthropogenic global warming (0-5 vs. 6-10). †$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$

Statistical numeracy showed a near-significant trend (perhaps because of the observed ceiling effects). The odds ratio for knowledge was 1.15 with 95% CI [.99, 1.34], indicating that the odds of agreeing with anthropogenic global warming tend to be roughly 2.7 times larger among individuals with the highest numeracy score as compared to those with the lowest numeracy score.

Predicted probabilities for belief in anthropogenic global warming across numeracy scores were plotted (Figure 16). For the bootstrapped regression, the means and standard deviations from Study 1 (i.e., probabilistically representative sample) were used.

Figure 16

Numeracy and Climate Change Beliefs



Note. Results depict the predicted probability for believing in anthropogenic global warming at different levels of knowledge and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

The plots again indicate a ceiling effect, especially among egalitarians. This may be because a large proportion of respondents already agreed that there is expert consensus about anthropogenic global warming. The result indicates that as numeracy score increases, an increasing trend for the national average group and individualist group can be expected.

Numeracy and Global Warming Risk Perception

A binary logistic regression model predicting whether one has above-average global warming risk perception was constructed in the same way. The outcome variable was whether one's global warming risk perception was below or above average, which was generated by

dichotomizing global warming risk perception variable (0-7 = Below average (0); 8-10 = Above average (1)). See Table 17 for results.

Table 17

Binary Logistic Regression on Global Warming Risk Perception

Variable	B	SE	Wald	OR	95% CI for OR
Numeracy	0.06	0.06	1.15	1.06	0.95, 1.19
Individualism	-0.41**	0.13	9.93	0.66	0.51, 0.86
Egalitarianism	0.77***	0.10	64.63	2.16	1.79, 2.60
Hierarchy	0.03	0.11	0.06	1.03	0.83, 1.28
Fatalism	0.18	0.11	2.64	1.20	0.96, 1.50
Age	0.00	0.01	0.13	1.00	0.99, 1.02
Gender	0.09	0.21	0.17	1.09	0.72, 1.65

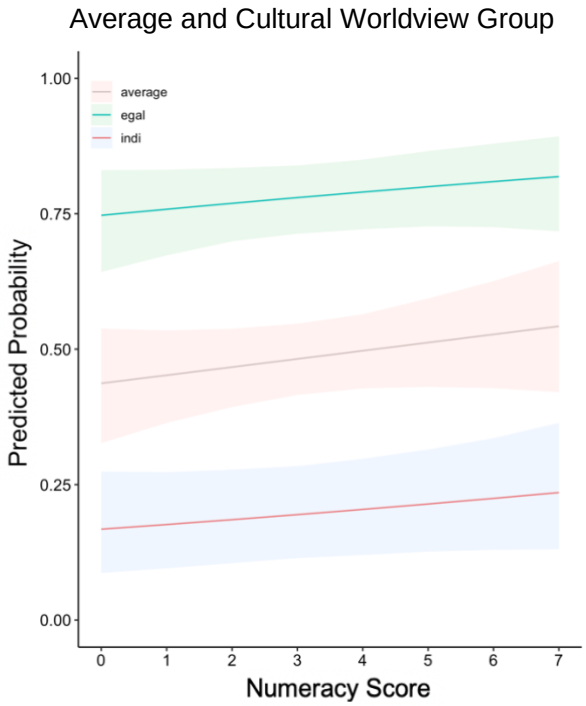
Note. Dependent variable was global warming risk perception dichotomized to represent whether one has risk perception above the mean of the current sample (0-7 vs. 8-10). *$p < .05$, **$p < .01$, ***$p < .001$

Although numeracy was not a significant predictor of above-average global warming risk perception in this study, the model was significant, and the results are still interpreted: the odds of individuals with the highest numeracy score to have above-average risk perception is roughly 1.5 times larger than those with the lowest numeracy score.

The predicted probabilities for above average global warming risk perception were modeled (see Figure 17). The outcome variable was a dichotomized version of global warming risk perception, representing whether one's global warming risk perception was below or above average (0-7 = Below average (0); 8-10 = Above average (1)). The means and standard deviations from Study 1 (i.e., probabilistically representative sample) were used.

Figure 17

Numeracy and Global Warming Risk Perception



Note. Results depict the predicted probability of having above-average global warming risk perception at different levels of numeracy and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

Similar to trends observed in the same analysis of Study 1, the results indicated that those with extreme cultural worldview indices tend to display perceptions that are more consistent with views associated with their cultural worldview. Again, it may be because numeracy has an indirect effect on risk perceptions via knowledge and beliefs.

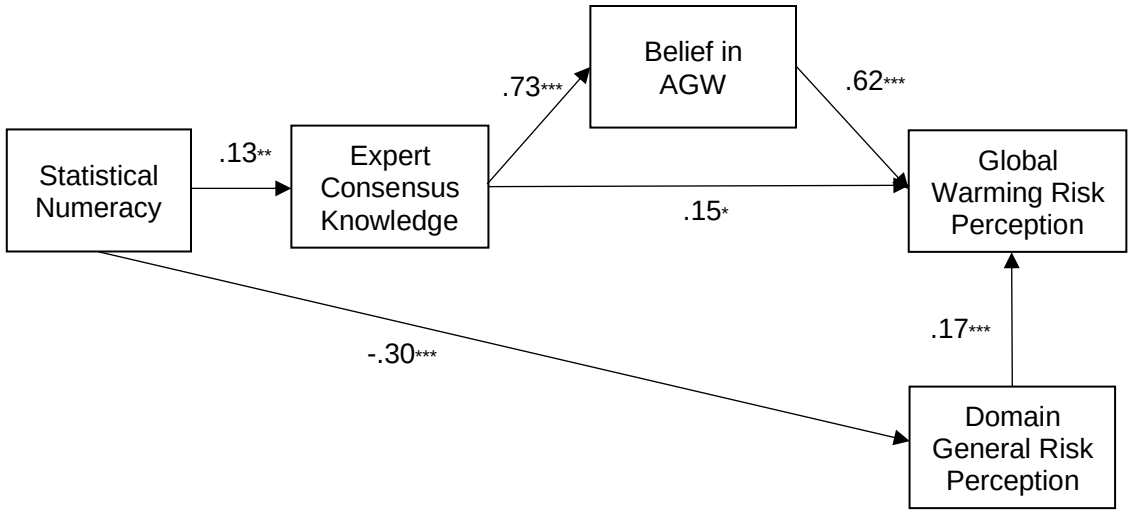
Does Numeracy Predict Relative Risk Attitudes?

Using Structural Equation Modeling, a new model integrating domain general risk perception was tested. For an exploratory purpose, a model without covariates (i.e., cultural worldview, demographics) was tested first (Figure 18). Indirect effects were estimated based on

bootstrap with 5,000 samples (Table 18). The model fit was as follows: $\chi 2(4) = 18.32$, $p = .00$, with CFI = .99, TLI = .96, SRMR = .07, RMSEA = .08 with 90% C.I [0.05-0.12]. RMSEA was close to mediocre, but the other indices were satisfactory (Hu & Bentler, 1999; Kline, 2011; MacCallum et al., 1996).

Figure 18

A Structural Equation Model with Domain General Risk Perception without Covariates



Note. Reported are standardized coefficients. Covariates (i.e., cultural worldview and demographic variables) were not included in the current model. *$p < .05$, **$p < .01$, ***$p < .001$.

Table 18

Indirect Effects (Standardized Coefficients) of Key Variables

Path	Estimate	SE	Bootstrap 95% CI
Knowledge → Belief → Global Warming Risk Perception	.45***	.06	.38, .62
Numeracy → Knowledge → Belief	.09**	.04	.04, .18
Numeracy → Knowledge → Global Warming Risk Perception	.02	.01	.00, .05
Numeracy → Knowledge → Belief → Global Warming Risk Perception	.06**	.02	.02, .11
Numeracy → General Risk Perception → Global Warming Risk Perception	-.05**	.01	-.09, -.03

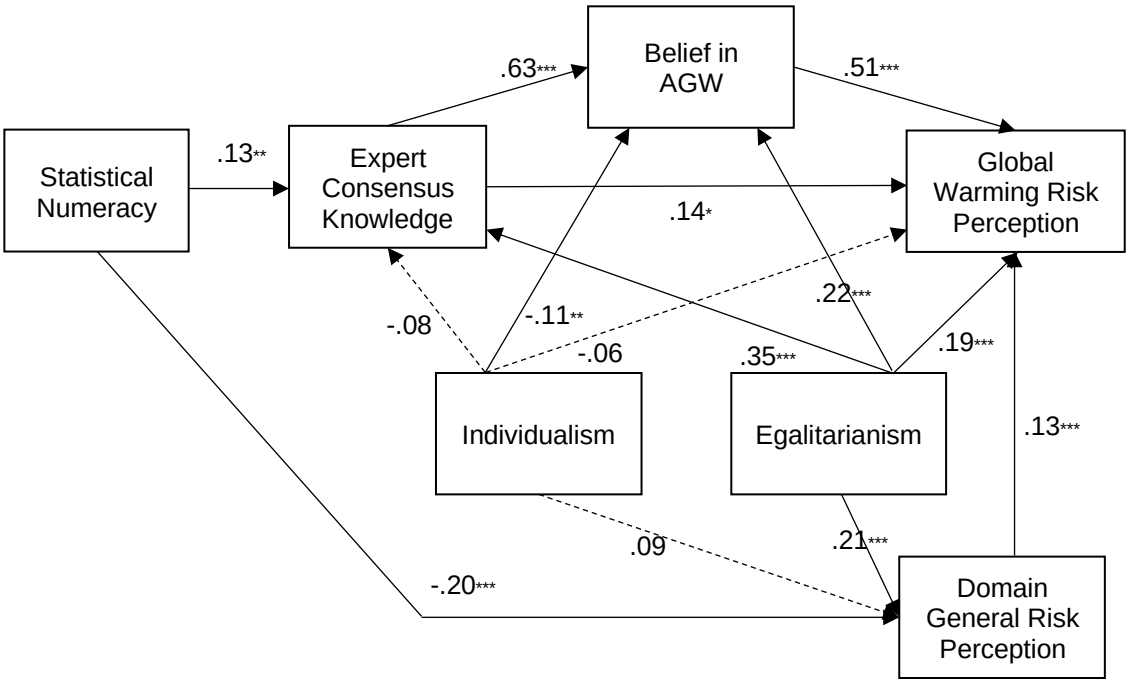
Note. Effects were estimated with 5,000 bootstrap samples. *$p < .05$, **$p < .01$, ***$p < .001$

Consistent with the model in Study 1, expert consensus knowledge was the strongest predictor of belief in anthropogenic global warming (β = .73, p < .001), and had a direct effect on global warming risk perception. Numeracy predicted expert consensus knowledge, independent of cultural worldviews and demographic variables (β = .13, p < .01). The results further indicate that numeracy is negatively related to domain general risk perception (β = -.30, p < .001), which in turn is positively related to global warming risk perception (β = .17, p < .001). The relationship between numeracy and global warming risk perception is fully mediated by domain general risk perception.

A model with the same structure but with covariates (i.e., cultural worldview, demographics) was tested next (Figure 19). Indirect effects were estimated based on 5,000 bootstrap samples (see Table 19). Numeracy was still negatively related to domain general risk perception (β = -.20, p < .001), which was positively related to global warming risk perception (β = .13, p < .001). The relations were independent of cultural worldviews and demographic variables. The model had a good fit: $\chi_2(4) = 8.04$, p = .09, with CFI = 1.00, TLI = .97, SRMR = .02, RMSEA = .04 with 90% C.I (0.00-0.09).

Figure 19

A Structural Equation Model with Domain General Risk Perception and Covariates



Note. Reported are standardized coefficients after adjusting for age and gender. The representation does not include paths from hierarchy and fatalism, which were as follows: Hierarchy → knowledge (β = -.09, p = .09), Hierarchy → Belief (β = .04, p = .30), Hierarchy → Global Warming Risk Perception (β = .02, p = .54), Hierarchy → General Risk Perception (β = .13, p < .05), Fatalism → Knowledge (β = .04, p = .37), Fatalism → Belief (β = .04, p = .22), Fatalism → Global Warming Risk Perception (β = .03, p = .33), Fatalism → General Risk Perception β =.08, p = .06). *p < .05, **p < .01, ***p < .001

Table 19

Indirect Effects (Standardized Coefficients) of Key Variables

Path	Estimate	SE	Bootstrap 95% CI
Knowledge → Belief → Global Warming Risk Perception	.32**	.05	.26, .46
Numeracy → Knowledge → Belief	.08**	.03	.03, .17
Numeracy → Knowledge → Global Warming Risk Perception	.02	.01	.00, .05
Numeracy → Knowledge → Belief → Global Warming Risk Perception	.04**	.02	.01, .08
Numeracy → General Risk Perception → Global Warming Risk Perception	-.03***	.01	-.05, -.01

Note. Effects were estimated with 5,000 bootstrap samples. *p < .05, **p < .01, ***p < .001

After controlling for cultural worldviews and demographic variables, the full model produced similar results to the previous model. Expert consensus knowledge was the strongest predictor of belief in anthropogenic global warming (β = .63, p < .001), and had a direct effect on global warming risk perception. Numeracy predicted expert consensus knowledge, independent of cultural worldviews and demographic variables (β = .13, p < .01). Numeracy was also negatively related to domain general risk perception (β = -.20, p < .001), which was positively related to global warming risk perception (β = .13, p < .001). Domain general risk perception fully mediated the relationship between numeracy and global warming risk perception.

Numeracy and Relative Risk Attitudes

A binary logistic regression predicting whether one has above average global warming risk perception was constructed. The outcome variable was relative risk perception dichotomized to represent whether one's difference score (between global warming and general risk perception) is above the mean or not (Table 20).

Table 20

Binary Logistic Regression on Relative Risk Attitudes

Variable	B	SE	Wald	OR	95% CI for OR
Numeracy	0.17**	0.05	9.96	1.19	1.06, 1.32
Individualism	-0.55***	0.12	22.00	0.58	0.46, 0.73
Egalitarianism	0.37***	0.09	18.84	1.45	1.22, 1.71
Hierarchy	-0.08	0.10	0.67	0.92	0.76, 1.12
Fatalism	-0.09	0.10	0.66	0.92	0.75, 0.13
Age	0.00	0.01	0.26	1.00	0.99, 1.02
Gender	0.05	0.20	0.07	1.05	0.71, 1.55

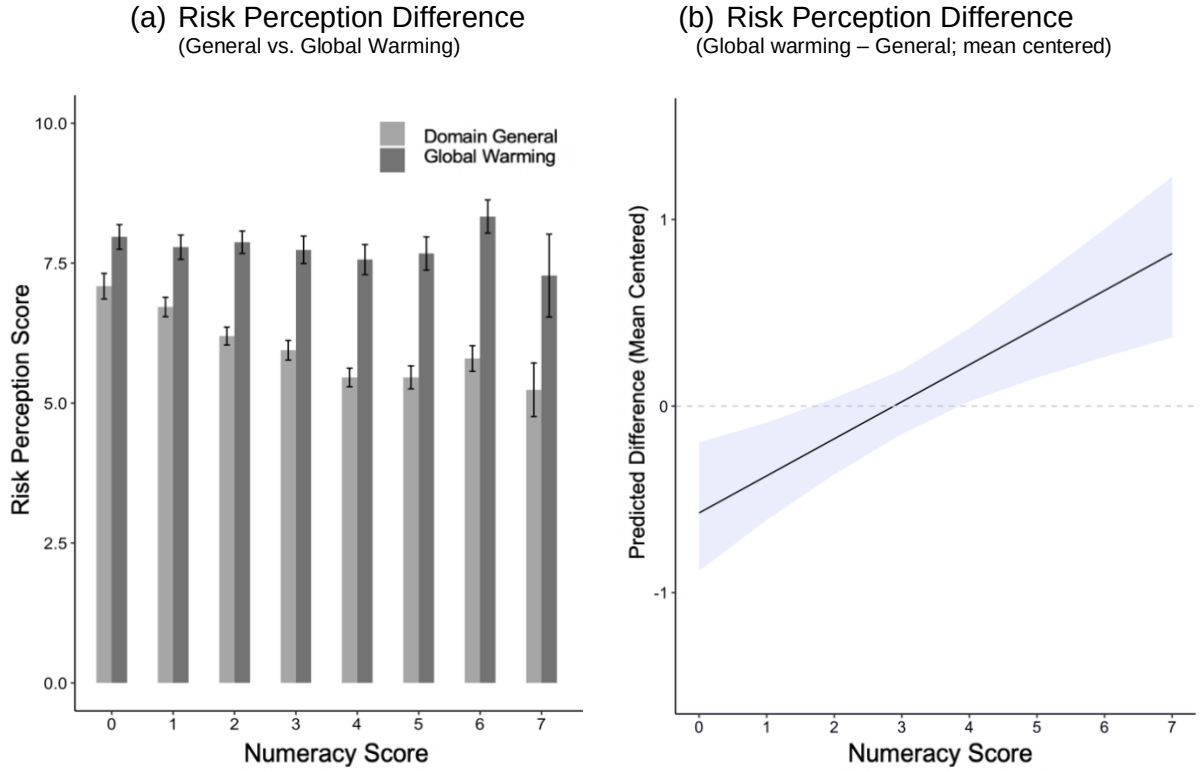
Note. Dependent variable was relative risk perception dichotomized to represent whether one's relative risk perception (i.e., global warming – general risk perception) is above the mean of the current sample. *p < .05, **p < .01, ***p < .001

As seen in Table 20, statistical numeracy was a significant predictor of *relative* risk perceptions (i.e., global warming risk perception as compared to general risk perception). The odds ratio for numeracy was 1.19 with 95% CI [1.06, 1.32], indicating that the odds of having above average relative risk perception for individuals with the highest numeracy score was roughly 3.3 times higher than those with the lowest numeracy score.

To illustrate the relationship between numeracy and relative risk perceptions, the average score for general and global warming risk perception were plotted respectively, with numeracy scores (Figure 20, Panel A). Additionally, the predicted *difference* in global warming risk perception and general risk perception (i.e., the latter subtracted from the former) were generated (Figure 20, Panel B). For interpretability, the outcome variable was centered around the global mean of the risk perception difference. Linear multiple regression with numeracy and cultural worldviews as the predictor variables was used. Cultural worldviews were adjusted to their means for the current data.

Figure 20

Numeracy and Differences in Risk Perception (Global warming vs. General)



Note. Panel A: Average score of general and global warming risk perception by numeracy score was plotted. Error bars represent standard errors. Panel B: Predicted differences in the two risk perceptions (i.e., global warming risk perception – general risk perception) were plotted. The dependent variable was centered around the mean. This linear multiple regression model used numeracy and cultural worldview indices as predictor variables, where cultural worldview indices were adjusted to each of their means. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

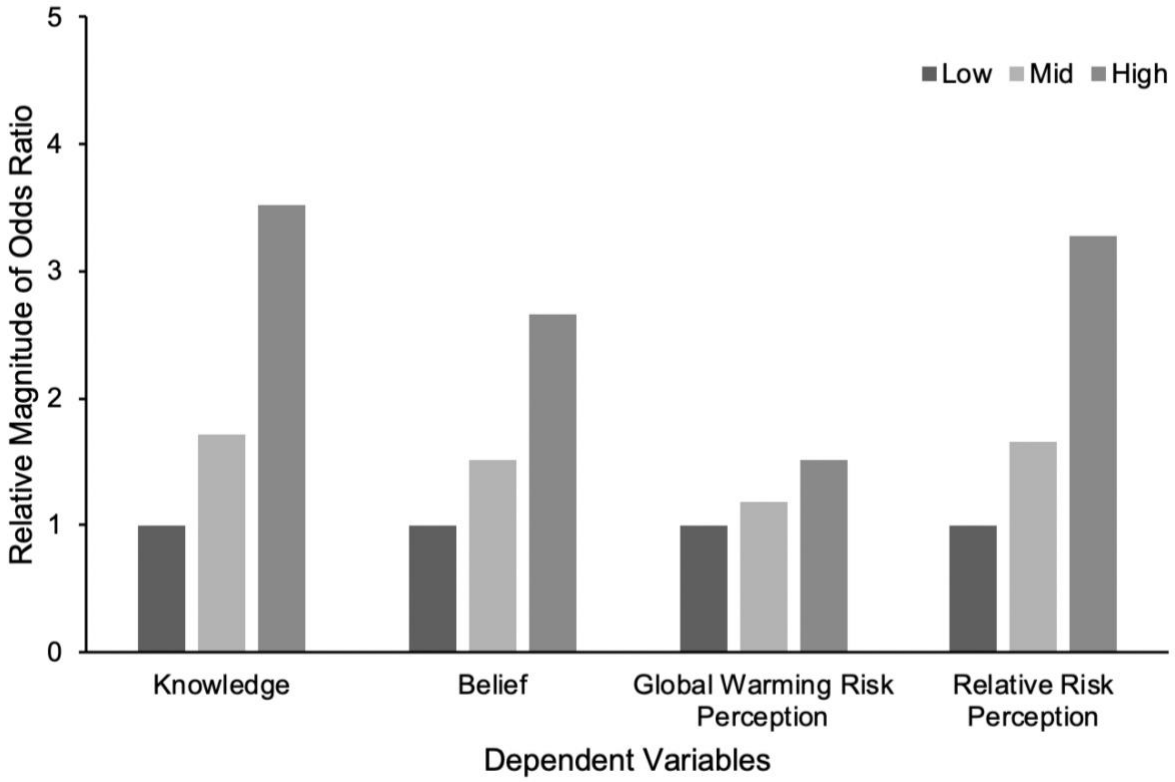
As compared to the average risk perception difference, highly numerate individuals tended to have higher concern for global warming, whereas less numerate individuals showed less variation in responses to risk perceptions (i.e., small differences between general risk perceptions and global warming risk perception).

Study 2: Summary

Five key findings of Study 1 were replicated in Study 2: A larger proportion of people as compared to Study 1 had accurate expert consensus knowledge and belief in anthropogenic global warming. Numeracy predicted expert consensus knowledge, and the integrated model suggested that numeracy had direct and indirect effects on the key outcome variables (i.e., belief and risk perception) independent of cultural worldviews. Relatively robust downstream benefits of numeracy on the key outcomes were observed (see Figure 21). Again, knowledge robustly predicted both belief and risk perception, exceeding the predictive power of main cultural worldview indices (e.g., individualism, egalitarianism). The set of integrated models that included general risk perception further suggested that numeracy was negatively related to general attitudes about risks (i.e., general risk perception), through which it had an indirect effect on risk attitude (i.e., global warming risk perception).

Figure 21

Numeracy, Knowledge, Belief, and Risk Perceptions



Note. Each bar represents relative magnitude of odds ratio at three different scores of numeracy (i.e., low = 0, mid = 3, high = 7) for having expert consensus knowledge, believing in anthropogenic global warming, having above average global warming risk perception, and having above-average relative risk perception (i.e., global warming – general risk perception).

The results indicate that although numerate individual may report only slightly higher levels of absolute climate change risk perceptions, when compared to all risks in general, results indicate that numerate people find the relative risk of climate change to be much higher as compared to less numerate individuals.

Chapter 4: General Discussion

The current set of studies are the first to test an integrated model of the psychological interrelations among general decision making skills (i.e., statistical numeracy and risk literacy), cultural worldview orientations, climate science knowledge, climate change beliefs, climate risk attitudes, and relative risk perceptions. Both studies were conducted with diverse adult participants living in the United States who varied widely and representatively with respect to essential demographic variables, including age, education, ethnicity, and gender. Results from both studies revealed a consistent and clear view of the underlying structure of interrelations among the variables. Given the many notable empirical findings, below I present a list of key findings, followed by a discussion of practical and theoretical implications.

(i) Most people tended to agree that there is broad consensus among experts that human activities are largely the cause of global warming.

(ii) Most people agreed that human activities were causing global warming.

(iii) Worldviews were not strongly related to whether or not someone agreed with human caused climate change or expert consensus.

(iv) Worldviews were mostly related to differences in how strongly people agreed with human caused climate change or expert consensus.

(v) Accurate knowledge about climate science (e.g., expert consensus about global warming) was by far the strongest predictor of differences in climate change beliefs and risk attitudes (e.g., 5-40 times more predictive power than specific worldviews).

(vi) On average highly numerate people were about 4 times more likely than less numerate people to have accurate knowledge and beliefs and were about 3 times

more likely to express above-average concerns about the relative risks of climate change.

(vii) Numeracy tends to robustly predict meaningful differences in whether or not people are likely to agree with human-caused global warming and expert consensus.

(viii) Numeracy is related to quantitative differences in the strength of agreement or disagreement with human-caused global warming and expert consensus.

(ix) The relationship between numeracy and risk attitudes tends to be indirect and so is unlikely to be evident in studies that neglect differences in knowledge or general risk perceptions.

(x) Numeracy tends to be related to lower general risk perceptions, such that numerate people are much more worried about climate change than they are about other risks, whereas less numerate people report that climate change is not much more worrying as compared to other risks in general.

(xi) There is no evidence of polarization as a function of worldview interactions with numeracy or with knowledge.

(xii) The influence of worldviews on beliefs and attitudes is largely, but not entirely, mediated by differences in knowledge (e.g., individualists are somewhat less knowledgeable than egalitarians).

Knowledge is Power

I found that knowledge tends to be the strongest predictor of belief and attitude about global warming risk perception. As such, the overall average predictive power of knowledge in the current study far exceeded that of any other factor, on average explaining approximately 20% more

variance than individual cultural worldview measures. Although the current study relied on only one relatively blunt self-report knowledge item to assess differences in understanding of expert consensus knowledge, the considerable predictive strength of the relation between knowledge and downstream beliefs and risk attitudes is noteworthy and consistent with some previous research. To the extent that the finding generalizes, it suggests that one of the single most important factors that is likely to determine the accuracy of one's climate change beliefs is the accuracy of one's understanding about the state of the science of climate change. This phenomenon is consistent with a *Knowledge is Power* hypothesis as described in Skilled Decision Theory—a theoretical psychological account of the primary cognitive mechanisms that tend to give rise to superior decision making in expert and non-expert reasoners (Cokely et al., 2018). In short, in addition to essential roles of general cognitive skills and deliberative heuristic use, the major source of differences in decision making quality tend to reflect differences in the extent to which decision makers have a representative understanding of the relevant knowledge, including domain specific understanding of material facts (e.g., climate science) and domain-general understanding of their own constraints and capabilities (e.g., a well-developed metacognitive sense of one's own personal values, feelings, skills, beliefs, biases, preferences, and responsibilities). To the extent that the findings generalize, efforts to provide transparent and accurate information about facts in the world including science, as well as efforts to enhance public understanding about information and risks may help individuals make better decisions.

Numeracy Does Not Polarize

I discovered that numeracy tends to predict accurate acquired knowledge and beliefs about climate change, independent of other variables that are known to induce biases in views about climate change. Consistent with Skilled Decision Theory, it suggests that numeracy tends to

promote acquisition of accurate knowledge, independent of factors that may induces biases, even in the domain of substantial controversy. Previous research suggests that climate change tends to have unique challenges that can impede the formation of accurate knowledge or beliefs (Hulme, 2015; van der Linden, 2015a; Weber & Stern, 2011). For example, experiential feedback on individuals' decisions based on their knowledge and beliefs are not always sufficient or immediate. In some cases, the consequences may even seem personally irrelevant because the implications of climate change may have separate dimensions (e.g., personal vs. societal). In these and other ways, climate change may provide an appropriate context for testing relations between factors that may shape biases in knowledge and belief, which may generalize to other controversial issues.

In both studies the model indicated that part of the relationship between worldviews and numeracy was complicated by the fact that knowledge largely (but not completely) mediated the relations between worldviews, beliefs, and attitudes. Considering the obvious presence of this robust relationship and other potential confounds of previous studies, there is good reason to think any potential interactions between numeracy and polarization are likely to generally be trivial or remarkably small (e.g., weak effects over a narrow subset of vulnerable individuals). Even if we assume the presence of an interaction effect that matched the strength of the reported interactions in the literature, the linear relationship between numeracy and knowledge was found to be about 19 times larger than the estimated magnitude of the significant interaction effects that have been reported in previous studies. To the extent that this robust relationship with numeracy and acquisition of accurate knowledge generalizes, even assuming the potential presence of previously reported interaction and bias, proper training efforts for statistical numeracy and effective transparent (understandable) climate knowledge risk communications seem likely to readily overcome small theoretical biases (Chen, 2020; Ybarra et al., 2017).

Limitations and Conclusions

As in all studies there are some notable limitations in the current study. First, although the measurements used in the present study appear to robustly capture differences in knowledge and beliefs, these assessments are based on single questions and thus there may be considerable room for future improvement. For example, developing a standardized psychometric measure for various priors (e.g., knowledge, general risk perceptions, social circle beliefs) with increased sensitivity that is also robust to threats like differential item functioning, may help parse out guessing and provide a higher-fidelity assessment of the differences, sources and causes of individuals differences, as well as the potential benefits of various interventions (e.g., how much better is risk communication A vs. B). This type of detailed development and standardization offers a host of benefits, allowing for both more detailed and more robust comparisons across different studies. It may also provide more precise estimates of the underlying causal dependencies as estimated in integrated cognitive models of the structural associations that shape biases and resiliency. Ultimately, these measures may facilitate development and evaluation of training efforts for promoting people's understanding about climate change and other risks. Indeed, given that the current investigation is a correlational study, these kind of instruments may prove particularly useful to the extent researchers want to validate the observed model (or test its robustness) via different experimental manipulations or training programs, with different groups and sub-populations.

Overall, the finding that numeracy robustly predicts accurate climate change knowledge and beliefs was only possible because of this integrated approach to testing a cognitive model of the structural relations. In some sense, failing to sample all the relevant variables may be a bit like failing to collect responses from a representative sample of people: Biased sampling of people,

processes, or materials tends to result in distorted and biased interpretations, which could further complicate public views about the trustworthiness of science in general (Brunswik, 1955; Dhami et al., 2004). Biased sampling of risk attitude measures also emerged as a likely confound in other previous research. Numerate people showed a very large relative magnitude in climate risk perception (how bad is climate change compared to other risk), whereas less numerate people who often appeared to be almost as worried about climate change as numerate individuals were found to simply be more worried about all risks in general. This finding may be consistent with the notion that numerate people, who are in turn more risk literate may have a better understanding of the risks they face in the work, as well as any potential benefits or costs associated with different courses of action. More generally, a representative sampling of people, processes, and priors may be necessary to develop and validate a representative understanding of the social, political, and behavioral systems under investigation.

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Appendix

Table S1

Items Used for Measuring Cultural Worldview

Measurement	Scale
Individualism	
The government puts far too many restrictions on what businesses and individuals can do.	1 (Strongly disagree) – 6 (Strongly agree)
Even the disadvantaged should have to make their own way in the world.	1 (Strongly disagree) – 6 (Strongly agree)
We are all better off when we compete as individuals.	1 (Strongly disagree) – 6 (Strongly agree)
Egalitarianism	
What society needs is a fairness revolution to make the distribution of wealth more equal.	1 (Strongly disagree) – 6 (Strongly agree)
Society works best if power is shared equally.	1 (Strongly disagree) – 6 (Strongly agree)
It is our responsibility to reduce differences in income between the rich and the poor.	1 (Strongly disagree) – 6 (Strongly agree)
Hierarchy	
The best way to get ahead in life is to do what you are told to do.	1 (Strongly disagree) – 6 (Strongly agree)
Society is in trouble because people do not obey those in authority.	1 (Strongly disagree) – 6 (Strongly agree)
Society would be much better off if the people in charge imposed strict and swift punishment on those who break the rules.	1 (Strongly disagree) – 6 (Strongly agree)
Fatalism	
The most important things that take place in life happen by chance.	1 (Strongly disagree) – 6 (Strongly agree)
No matter how hard we try, the course of our lives is largely determined by forces beyond our control.	1 (Strongly disagree) – 6 (Strongly agree)
For the most part, succeeding in life is a matter of chance.[4]	1 (Strongly disagree) – 6 (Strongly agree)

[4] The item was excluded from the analysis.