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ARTICLE

Scientifically Together, Politically Apart?

Epistemological Literacy Predicts Updating on Contested Science Issues

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Abstract
Science education is generally perceived as a key facilitator in cultivating a scientifically literate society. In the last decade, however, this conventional wisdom has been challenged by evidence that greater scientific literacy and critical thinking skills may in fact inadvertently aggravate polarization on scientific matters in the public sphere. Supporting an alternative "scientific update hypothesis," in a series of studies (total $N=2087$), we show that increased science's epistemology literacy might have consequential population-level effects on the public's alignment with scientific results. In one exploratory study and a pre-registered national online survey, we first show that understanding scientific epistemology predicts refusal of pseudoscientific beliefs and higher scores in a methodology of science test. We also find and replicate a propensity for epistemologically literate citizens to endorse the norm of belief updating and the communicated scientific consensus following both ideologically congruent and incongruent scientific results. Notably, after 2 months of first being presented with scientific results on politically controversial issues, a one standard deviation higher score in epistemological literacy is associated with a 14% increase in the odds of individuals switching their beliefs to align with the scientifically communicated consensus. We close by discussing how, on the face of ideological incongruity, a general understanding of scientific epistemology might foster the acceptance of scientific results, and we underscore the need for a more nuanced appreciation of how education, public comprehension of scientific knowledge, and the dynamics of polarization intersect in the public sphere.

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1 Introduction

In the science and education literature, it has become common to contrast the promise of promoting a general understanding of the nature of science with the specific efforts to educate the public around key scientific concepts and models, such as a basic understanding of the spread mechanisms of airborne diseases or the main ideas behind the theory of evolution (Sinatra & Hofer, 2021). Despite the potential social value of a public with a better understanding of very specific scientific models, including better-informed decisions on that specific domain (Von Winterfeldt, 2013), the inherent limitations of providing a universal education in numerous scientific fields to the citizenry have historically provided justification for maintaining, at the bare minimum, some level of general public understanding of science as a special form of epistemic (i.e., knowledge-seeking) activity (McComas, 2002; Dagher & Erduran, 2016).

At present, it is not rare that conflicting visions of science appear in a series of controversies that have an impact on public policies (Skolnick-Weisberg et al., 2021; Kovaka, 2021; Pinillos, 2018). Controversial socioscientific issues typically involve some form of decisive disagreement, leading to divergent positions in public policy and manifestly different moral judgments. By their very nature, public responses to socioscientific controversies tend to appeal to differing views on the nature of the relevant epistemic or scientific authority while also evoking emotional reactions because of perceived threats or worries about potential risks and benefits (Colombo et al., 2016; Rekker, 2021). Consider the origins of global warming, the safety of nuclear energy, the healthiness of genetically modified foods, and the public perception of economic or epidemiological recommendations—many of the controversies that arise around these issues seem to invoke a certain conception of what is scientific, what is not, and what implies that certain results are presented as scientific (Pasek, 2018; Suldovsky et al., 2019; Pils & Schoenegger, 2024). The present research was designed to delve deeper into the relationship between understanding the nature of scientific knowledge, what we here call "science's epistemology," and the adoption of polarized beliefs regarding contentious socioscientific issues. In this context, lay science's epistemology can be broadly characterized as the general view of the public regarding the nature of scientific inquiry as a social institution, the knowledge value of scientific theories, the distinctiveness of scientific hypotheses, or the status of provisional results (Hofer, 2000; Thomm et al., 2015).

What part does greater literacy in the epistemology of science play when it comes to embracing polarized opinions on socioscientific controversies? A thorough review of the literature gives reasons to be hopeful but also raises concerns. On one side, an influential line of research has consistently shown how, among US citizens, scientific literacy, as typically measured by the variables used by the National Science Board or Eurobarometer surveys (Pardo & Calvo, 2004), is linked with more polarized beliefs on a series of socioscientific hot topics, such as anthropogenic climate change (Kahan et al., 2012). Other studies conducted in the USA have replicated this finding: For example, a re-analysis of the General Social Survey data from 2006 to 2010 (Drummond and Fischoff, 2017) discovered that a higher level of education, particularly a higher level of science education and science literacy, predicted more polarized beliefs on scientific issues along political or religious lines. Dan Kahan has famously explained this finding by appealing to what he terms a "conflict of interest" that individuals confront. That is the conflict between, on the one hand, forming beliefs that fit with the best science available and, on the other hand, forming beliefs and adopting positions well aligned with the social group individuals most strongly identify with, such as political or religious groups (Fasce et al., 2023). By pointing out that science-educated citizens frequently leverage their sophisticated understanding of science in support of their identity group on contentious issues, in a form of identity-protective cognition (Kahan et al., 2013), Kahan (2018) has even asked whether "*smart people are ruining democracy.*"

On the flip side, other measures of familiarity with science have yielded more promising results (Pennycook et al., 2023): For example, field-specific measures have occasionally been shown to predict more scientifically adjusted views, regardless of ideology (e.g., a domain-specific understanding of climate change, McCaffrey & Rosenau, 2012). Moreover, Kahan and his collaborators also found that "science curiosity," a particular desire to consume science-related media for one's own education, might counteract politically biased information processing (Kahan et al., 2017), an effect that they did not find for ordinary science intelligence as measured by the standard general science knowledge test. Relatedly, Lombrozo et al. (2008) and Skolnick-Weisberg et al. (2021) presented relevant data pointing to a link between an increased understanding of the nature of scientific knowledge and the acceptance of science around controversial issues such as the theory of evolution or the reality behind global warming, while Carter and Wiles (2014) also demonstrated that, after one semester of college, biology students' responses to the *Thinking about Science Survey Instrument* (TSSI) tended to improve, with those improvements being associated with a greater acceptance of the theory of evolution and global climate change.

If the right kind of scientific literacy appears then to be a crucial factor, the reasons why an enhanced understanding of scientific epistemology could have these positive effects are multiple. It has been argued, for instance, that science denialists tend to promote a self-serving view of scientific knowledge (Staley, 2019), a view that is typically not well anchored in how science really works. In addition, an improved understanding of the hierarchy of scientific proof and scientific evidence (Anderson, 2011) could perhaps attenuate the polarization dynamics that are sometimes linked to a biased and caricatured view of the evidential value of scientific results. A better understanding of the nature of scientific knowledge and scientific evidence might help promote a superior, if not unconditional, form of trust in the results of scientific activity (Gerken, 2022), thus protecting the public from what is one of the best predictors of science denialism, namely, mistrust in the scientific community (Fasce & Picó, 2019). In a recent study, O'Brien et al. (2021) provided evidence for a better-calibrated form of trust by convincingly showing that, whereas "blind" trust in science may lead to the spread of pseudoscientific beliefs, an enhanced understanding of scientific methodology counteracts this effect by reducing trust in scientifically looking but unwarranted claims. Beyond this "confusion-based account" (Fasce, 2022), adopting a more nuanced view of how evidence is exchanged and scrutinized in scientific consensus-building could also help reduce the risk of falling prey to polarizing dynamics. By counteracting a distorted view of science that is often useful for sowing distrust of inconvenient scientific results, a clearer comprehension of the characteristics of scientific knowledge can equip the public to resist harmful denialism.

Drawing upon theoretical frameworks from educational psychology, philosophy of science, and the experimental study of social cognition, the present work uncovers relevant influences that contribute to the public's perceptions and interpretations of scientific information. More specifically, we examine a question that is both timely and socially consequential, namely, whether an improved understanding of science's epistemology has an impact on how science communication on socially contested topics is processed and whether this could be a driver or instead a bridle, on polarization dynamics. A synoptic table outlining the separate studies and key findings is presented in Table 1. Our data and materials, as well as pre-registered analysis plans, are available on the Open Science Framework https://osf.io/m86fq/?view_only=762cc004d1a048a7997df38619ed379f.

Table 1 Overview of studies. Objectives, key findings, sample sizes, and replication status are highlighted for each study

Study	Objective	Sample	Key findings/hypotheses	
Development of Lay Science Epistemology Survey Instrument (LSESI)	Measure epistemological literacy	493 participants, Spain	- LSESI demonstrated adequate internal reliability - LSESI predicted higher scores on a scientific methodology test - LSESI predicted rejection of pseudo-scientific claims	Section 2 & Appendix Sect. 1
Exploratory study	Explore the relationship between epistemological literacy and polarized beliefs	577 participants	- Epistemological literacy predicts a greater willingness to update beliefs on controversial scientific issues - Neither greater education nor higher epistemological literacy scores were predictive of more polarized beliefs	Section 3 & Appendix Sect. 2.3
				As predicted?
Pre-registered national survey	Replicate and confirm exploratory findings	1017 participants, Spain	Epistemological literacy (H1) predicts greater willingness to update beliefs and (H2) higher alignment with the scientific view, regardless of ideological congruence H3a: Greater education does not predict polarization on controversial issues H3b: Greater epistemological literacy does not predict polarization on controversial issues	H1: Yes (Sect. 4; appendix Sect. 3.2) H2: Yes (Sect. 4; appendix Sect. 3.5) H3a: Yes H3b: No (Sect. 4 and appendix Sect. 3.8)
9-week follow-up	Assess the long-term persistence of belief change	858 participants	H4: Epistemological literacy linked to sustained belief change after 9 weeks - Epistemological literacy was linked to reduced epistemic mistrust and greater recognition of scientific consensus	H4: Yes (Sect. 5)

2 Measurement of Lay Science's Epistemology

Efforts to capture competence in epistemology in the public have been numerous, some of them preceding the present work for several decades. In our view, two main lines of research have run parallel. One line originated in educational psychology and developmental psychology and has gone under different names, such as "personal epistemology" (Barzilai & Weinstock, 2015; Barzilai & Zohar, 2014) or "epistemic cognition" (Sinatra et al., 2014). Casting a net on beliefs about the nature of knowledge, criteria for knowledge evaluation, and strategies for knowledge acquisition, the field has also focused on how these beliefs influence learning and academic achievement. Following this line of research, several studies have uncovered how individuals' beliefs about knowledge evolve over time, from a simplistic view which sees it as absolute and detached to a more complex understanding of knowledge, first as subjective and then as dependent on the examination of alternative viewpoints and the critical scrutiny of evidence.

A second line of research, which we could refer to as "the public understanding of the nature of science," has been more connected to the sociology of science, educational research, communication studies, and applied philosophy of science (Davies, 1958; Miller, 2004; Kampourakis, 2016; Alters, 1997). Its primary focus has been the measurement of people's beliefs and attitudes regarding science as a body of knowledge, a method, and a social institution. Using national and cross-national studies, this line of research yielded some of its classic findings, including the discovery that a substantial portion of the public lacked a fundamental understanding of the nature of science, the uncovering of sociological factors that may influence that understanding, and the need to improve science education and communication efforts (Cheung & Erduran, 2023; Miller et al., 1997).

We wanted to employ a measurement method that would take into account previous efforts but should also be practical to the administration of online population surveys. After detecting a series of shortcomings for our purposes in previous survey instruments, we decided to draw on the attempts of Lombrozo et al. (2008) and Skolnick-Weisberg et al. (2021) and add to theirs a more diverse and extensive list of items. Supplementary Information (S.I.1.) describes in more detail our justification, strategy, and analyses. We submitted our initial list of 50 items, to the judgment of 17 professional historians and philosophers of science to broadly check for the ecological and cognitive validity of the items. Experts flagging one of the items a sufficient number of times or at least four experts giving proof of disagreement on one of the statements left us with a final list of 39 items.

After recruiting a sample of Spanish participants through online social media as well as through the Prolific platform ($N=493$, $M_{age}=33.5$, female = 45%), we tested the final list of items on their internal reliability and their relation to a number of covariates to further corroborate their external validity: refusal of pseudoscientific beliefs (Fasce et al., 2021), scores in a science methodology test (adapted from O'Brien et al., 2021), and having had some form of science education in university. We converged on an 18-item *Lay Science's Epistemology Survey Instrument* (*LSESI*) overlapping to a substantial 50% with the 20-item *Nature of Science Scale* used by Skolnick-Weisberg et al. (2021) and corresponding to the recognition that science is a social, open process subject to a number of institutional checks, where new questions almost always arise, and evidence plays a role in guiding this process (supplementary information 1.4; Table 2) (Table 2).

Table 2 Survey items illustrating constructs linked to scientific epistemology. This table provides examples from the Lay Science Epistemology Survey Instrument, Science Methodology Test, and Short Pseudoscientific Belief Scale

Construct	Example items	Response format
Lay Science Epistemology Survey Instrument	- "When scientific theories are based on highly precise experiments, they no longer get modified." (reverse scored) - "Peer review is the process by which at least two evaluators enter another scientist's laboratory to review whether the instruments are well calibrated." (reverse scored) - "Some mathematical models of phenomena such as meteorology, economics, or health can predict what will happen even if they are not precise." - "A scientist does not have to accept theories and results from others unless they have derived each conclusion themselves." (reverse scored)	Likert scale (1 to 5)
Science Methodology Test	- "In an experiment, the independent variable is…" (multiple-choice options provided) - "Two studies attempt to estimate the average caffeine content of an energy drink…" (multiple-choice options provided) - "To scientifically test a drug that is known to be safe when you want to test whether it can be used to cure a different disease, what is the best way to test its efficacy?" (multiple choice)	Multiple choice
Short Pseudoscientific Belief Scale	- "It has been scientifically demonstrated that some people have extrasensory abilities (such as telepathy or precognition)." - "The collective memory inherited and shared by organisms belonging to the same species ("morphic field" or also "morphic resonance") explains several biological phenomena." - "There is archeological evidence of ancient contacts with 'astronauts' or 'space visitors' (for example, in cultures such as Sumerian, Egyptian, Mayan or Nazca)."	Likert scale (1 to 5)

3 First Exploratory Study

Next, we devised a study to explore the relationship between embracing science's epistemology and adopting polarized attitudes toward socioscientific issues.

3.1 Methods

3.1.1 Participants

We recruited 577 adult participants who resided in Spain and who would like to participate in a 15–20-min survey through the survey platform Prolific in exchange for economic compensation. Of these, 536 (mean age 31.4 years old; 49% female) passed the attention check.

3.2 Measures

3.2.1 Pre-test Beliefs

Participants were surveyed on four, randomly assigned, out of six controversial science topics on the public agenda, selected so as to keep a balance of issues that mobilize both the right and the left among the Spanish public: anthropogenic global warming, the safety of nuclear energy, the economic effects of unregulated immigration, GMO's safety, the effects on criminality of the legalization of drugs, and the effects of rent control on housing availability. Each participant had to report, first of all in the study, their belief or perception around a factual question surrounding four randomly selected issues (e.g., "In your opinion, how much do you think the temperature will increase (or decrease) after the next 20 years due to human industrial and economic actions that emit greenhouse gases, if those gases are not reduced […] by at least a quarter by the year 2030?").

3.2.2 Science Communication

Next, we presented them with a minimal form of science communication, a short paragraph describing a finding in the literature that conveys the majority view on the field regarding each one of the six issues, accompanied by a reference to the expert source (e.g., "Researchers on the safety of nuclear energy have reached the conclusion, accepted by other researchers, that nuclear energy poses far fewer risks to safety and the environment than the energies mostly used today in most countries, including Spain. These researchers concluded that nuclear energy is at least more than 100 times safer than the energy mostly used in Spain today (Source: Our World in Data, University of Oxford)"). This was followed by a multiple-choice comprehension question to make sure participants understood the brief scientific communication.

3.2.3 Change of Heart, Post-communication Beliefs, and Covariates

For each one of the four randomly assigned controversial issues, they were asked to report their beliefs again on the topic, as well as a series of questions (see supplementary materials) including *belief updating norm*, how much they believed one should update their beliefs based on the reported scientific testimony; *support for science-based policy*, how much they agreed that the government should follow the scientific advice emanating from these results; *perception of epistemic vice*, how much they agreed or disagreed with a series of statements purported to measure their perception of prejudice and bias in the scientific community behind the communicated result (all of the above items displayed on rating scales from 1 = absolutely disagree to 6 = absolutely agree); *perception of moral riskiness*, how good or how bad they would judge it to be if these scientific results turned out to be wrong but policymakers still followed them (6-point Likert item anchored at 1 = absolutely good to 6 = absolutely bad); *perception of scientific consensus*, how broad they perceived the scientific consensus on the reported result (slider item from 0 to 100%); and *online sharing*, how willing would they be to share the above presented scientific result on their online social media profiles (6-point Likert item).

3.2.4 Epistemological Literacy and Demographics

Participants were then presented with the 18-item Lay Science's Epistemology Survey Instrument (5-point Likert scale from 1 = very much in disagreement to 5 = very much in agreement) and the 6-item multiple-choice Scientific Methodology Test that was already used in the survey instrument calibration phase. Before leaving the study, they were thanked and asked to report basic demographic statistics (age, gender, municipality, and education level) and how they self-identified on a left–right political spectrum going from 1 = "extreme left" through 5 = "center" until 9 = "extreme right" rating.

3.2.5 Mysideness

Based on the resulting ideological differences, we computed a measure of the degree of myside incongruence for each one of the issues for individual participants. This was the result of conditionally reversing the 1 to 9 score on political self-identification depending on whether the communicated science was incongruent to the left or incongruent to the right (reversed score).

3.3 Results

Participants failing to answer the different comprehension questions following each of the four brief science communication excerpts, as well as two participants showing extremely implausible response times, were excluded, leaving us with a total of 480 participants ($M_{age} = 31.5$, 50% female) for analysis. Of these, 61% self-identified with a value left-of-center of the political spectrum, 19% self-identified with the political center, and an additional 18% self-identified with a value right-of-center of the political spectrum.

3.4 Primary Analyses

Education, Epistemological Literacy, and Polarization Both before and after being presented with the scientific communications, participants' perceptions and beliefs around each one of the socioscientific controversies could be generally predicted in relation to their left–right political self-identification. Pairwise comparisons of the means using Tukey's honestly significant difference procedure indicated only one significant ideological comparison, the comparison between self-identified left-wing participants and self-identified right-wing participants, across all socioscientific issues except GMOs (for which $p\ adj = 0.10$ *before* and $p\ adj = 0.24$ *after*). Centrist responses were most of the time statistically indistinguishable from rightist responses but not always distinct at a significant level from left-wing participants (supplementary tables 2.1. and 2.2.).

Epistemological literacy (Cronbach's $\alpha = 0.80$) appeared as a clear predictor of stronger endorsement of belief updating following the intervention. For each one of the hot-button issues, participants who scored higher on epistemological literacy tended to support more strongly the statement "One should update one's beliefs about [issue X] based on the work of these scientific researchers" and regardless of political self-identification (*myside-ness*). This showed up clearly when fitting a repeated measures linear mixed model with "participant" and "issue" as random variables while controlling for various demographic characteristics. While mysideness (political self-identification in relation to ideologically incongruent scientific results) was a strong predictor of being less willing to update one's beliefs (β[1] $= -0.20$, $t(1910) = -9.96$, $p < 0.001$), higher scores in epistemological literacy were still clearly predictive of increased endorsement of updating one's beliefs ($\beta = 0.14$, $t(1910) = 4.34$, $p < 0.001$; supplementary Table 2.3.).

Looking at participants' reported beliefs after they were presented with the scientific communication, we find that agreement with the belief updating norm was also a good predictor of whether or not they had actually switched their views in a change of heart to match the scientific results. To test this, we coded as a yes/no binary variable representing holding a view as the one communicated in the presented scientific result for each one of the issues, where "yes" was coded as the result of embracing the polarity of the view regarding four of the issues (e.g., immigration as having net positive economic effects instead of negative effects, rent control as being perceived as pernicious instead of beneficial for tenants) or as sharing a numeric belief in the range of the communicated result for two of the issues (e.g., perceiving nuclear energy to be at least 100 times safer relative to the main source of energy currently employed, perceiving the amount of anthropogenic global warming in the next two decades to be poised to be in the range between 2 and 3 °C from pre-industrial levels if nothing was done to curtail emissions). The percentage of participants who completely switched their beliefs after reading the scientific communication ranged from a maximum of 38% for anthropogenic global warming (due to a large extent to an initial overestimate of the amount of warming) to a minimum of 11% for a positive reversal in the perception of the effects of drugs' legalization on criminality. Fitting a repeated measures logistic mixed model based on the binomial error distribution, where the binary variable of having changed one's mind (vs. not) serves as the dependent variable and "issue" and "participant" are treated as random variables, shows

[1] In all the presented regression models, continuous predictors were mean-centered and scaled by one standard deviation, but the outcome variable was not standardized unless stated otherwise. See the supplementary appendix for details of model specifications.

that endorsement of the norm of updating one's beliefs in relation to each one of the specific scientific results is a substantial predictor of actually switching the polarity of one's beliefs or calibrating it into the scientifically communicated range ($\beta = 0.33$, $z = 5.07$, $p < 0.001$) (supplementary Table 2.4.1.).

As many participants scoring high in scientific epistemology (*LSESI*) already embraced the same belief as the one communicated in the scientific result, greater scores in the *LSESI* are not predictive of switching beliefs per se ($\beta = -0.07$, $z = -1.07$, $p = 0.29$). Science epistemology scores are, however, predictive of holding the scientifically communicated result after it has been communicated ($\beta = 0.47$, $z = 3.73$, $p = < 0.001$). Thus, we devised an analytical strategy in which already holding the scientifically correct response before it has been communicated can be modeled as a suppressor variable, a variable that masks the true effect of greater epistemological literacy on updating one's beliefs.[2] Thus,

Holding the scientific belief$_{\text{(after it has been communicated)}}$ = Holding the scientific belief$_{\text{(before)}}$ + Epistemological literacy + 1|Issue + 1|Participant.

was fitted as a logistic regression mixed model. Results suggest that switching to a view congruent with the scientifically communicated result is actually linked with higher epistemological literacy, once you control for the fact that citizens with more familiarity with the epistemology of science also tend to be already better informed in the first place ($\beta = 0.16$, $z = 2.16$, $p = 0.03$), an effect that proves to be robust to the inclusion of demographic covariates (age, gender, educational level) and even ideological incongruence, itself a strong negative predictor ($\beta = -0.50$, $z = -6.44$, $p < 0.001$, supplementary Table 2.4.2.).

Are participants with a higher educational level or with a higher score in epistemological literacy more apt to hold extremist perceptions on these polarized issues, or are they less apt to polarize? A measure of deviation from the ideological median response for each one of the pre-test beliefs[3] was used as a dependent variable in a repeated measures linear mixed model. Participants who deviated more could be seen in principle as more extreme or more polarized, irrespective of the correctness or adequacy of their responses. Neither greater education nor greater science's epistemology scores were predictive of more polarized beliefs while controlling for demographic characteristics and degree of self-reported ideological extremity (the absolute value of the scaled responses of participant's self-positioning on the left-and-right axis). We obtained this result both for the data obtained before participants were presented with the scientific testimony (epistemological literacy $t(1910) = 1.23$, $p = 0.22$; educational level, $t(1910) = -0.96$, $p = 0.34$; ideological extremity, $t(1910) = 5.10$, $p < 0.001$, $\beta = 0.12$) and for the reported beliefs after participants read the scientific communication (epistemological literacy $t(1910) = 0.57$, $p = 0.57$; educational level $t(1910) = -0.68$, $p = 0.49$; ideological extremity $t(1910) = 2.67$, $p = 0.01$, $\beta = 0.06$. Supplementary information 2.5. for details and additional analyses).

[2] For obvious reasons, since most of the time one should not reverse a belief which, according to the new data, is already correct.

[3] Specifically, we used the scaled individual deviation from a central ideological point (halfway between left and right) of the sample, for each one of the pre-test beliefs. We simply calculated the median responses of participants who self-identify as left-wing and participants who self-identify as right-wing and traced a central point between those values, but other techniques of calculating the central response yielded similar results.

3.5 Secondary Analyses

Given the different covariates that we included as part of the survey, what explains support for following the scientific recommendations beyond epistemological sophistication? Perhaps, the most predictive (negative) factor was the perception of epistemic vice at the root of the research community behind the communicated results ($\beta = -0.37$, $t(1907) = -12.47$, $p < 0.001$, S.I. 2.6) a result congruent with the large literature on the effects of trust on knowledge communication (Gauchat, 2012; Levy, 2019; Miller, 2004; Sperber et al., 2010). This effect was closely matched by participants' representations of the scientific consensus ($\beta = 0.35$, $t(1907) = 13.24$, $p < 0.001$), suggesting that, contrary to post-truth rhetoric, how participants conceived of scientists agreeing on or refusing to accept the scientific results was, in fact, still a very crucial factor. Perceptions of moral riskiness ($\beta = -0.13$, $t(1907) = -6.56$, $p < 0.001$)—specifically, the belief that the recommendations could be particularly harmful if the results were wrong—were also linked to individual hesitancy to support science-based guidelines. This finding aligns with recent work on the folk ethics of belief (Cusimano & Lombrozo, 2021).

3.6 Discussion

For a series of questions, participants showed a marked propensity to align their responses with regard to their political allegiances, to that extent corroborating the *mysideness* of perceptions around scientific issues that become politicized on the public agenda. However, contrary to the "conflicts of interests" hypothesis, participants with greater education or better understanding of the knowledge-generating process of science did not show any clear signs of providing more extreme or polarized responses, neither before nor after being presented with a short scientific communication regarding each one of the issues. In fact, a greater understanding of the social and institutional nature of scientific knowledge was linked to greater endorsement of the idea that one should update one's beliefs following scientific results, even when they are incongruent with one's political ideology. In addition, when controlling for whether participants already held the view contained in a short piece of scientific communication, such epistemological literacy also predicted the acquisition of beliefs matching the communicated scientific results.

4 Pre-registered National Online Survey Replication

Because our analyses were mostly of an exploratory nature and because they could have been the result of a somewhat skewed sample in certain respects (e.g., on age, political self-identification, or educational attainment), we sought to replicate our initial findings in a nationally representative sample of the Spanish population.

4.1 Methods

4.1.1 Participants

Members of a nationally representative online panel of the Spanish population, who were at least 18 years old, were invited to take part in a 15-min study on science and the views of the public (see supplementary information 3.1. for information on panel constitution and participants' demographics as compared with official statistical data).

4.1.2 Measures

The survey replicated for the most part the previous study except for a few items. It followed the structure of first asking the original *pre-test beliefs* of participants in relation to four controversial scientific issues presented in a random order, of which two issues are perceived as ideologically incongruent for most left-wingers in Spain (nuclear power safety and effects of rent control) and the other two are perceived as ideologically incongruent for most right-wingers (economic effects of immigration and anthropogenic global warming). Participants were this time also asked to report their level of agreement or disagreement with 5 items of the Short Pseudoscientific Beliefs Scale (Fasce et al., 2021), after which all participants were presented with each of the four brief scientific communications on the contentious issues in a random order, followed by a series of questions as in the previous study: First, a multiple-choice comprehension question was asked to ensure participants understood the short text presenting the scientific conclusion. Then, participants were queried again about their belief on the given issue, after which they were presented with a series of specific questions for each one of the scientific results, measuring the following variables already described for the previous study: *support for belief updating norm*, *support for science-based policy*, *perception of epistemic vice*, *perception of moral riskiness*, and *perception of scientific consensus*. In addition, participants were asked to complete the 18-item Lay Science's Epistemology Survey Instrument and to optionally report their political ideology. Other demographic information, including age, gender, education level, Spanish region, and municipality size, was obtained from the survey company's records.

4.2 Results

In total, 1017 participants completed the study, of whom 931 ($M_{age}=47$ years old; 50% female) passed a basic attention check toward the end of the survey. Of these, 4% of participants opted out of the ideological self-identification question, the rest 51% self-defined as leftist, 21% chose the center value, and 27% self-defined as right-wingers. Not passing the comprehension questions for each one of the four scientific communication excerpts was a further (pre-registered) reason for exclusion. In total, 692 participants ($M_{age}=45.5$; 51% female; 51% without a higher education degree; 26% self-identified as "right," 21% "center," 52% "left") passed all the comprehension checks and were entered into the following analyses.

4.2.1 Ideological Assortment of Beliefs

Pairwise comparisons of the means using Tukey's honestly significant difference procedure indicated that there was always a statistically significant, and most often substantial, difference between the initial beliefs of supporters of the right and the initial beliefs of supporters of the left (supplementary information 3.2).

4.2.2 Epistemological Literacy and Change of Heart

We replicated the logistic mixed model that was fitted in our previous study to predict whether participants embraced the communicated scientific results once they had been presented, sometimes reversing their previous views. The model again included the binary value of whether their previously reported belief was already in line with the communicated consensus, along with science's epistemology (18 items, Cronbach's $\alpha = 0.77$), age, gender, and educational level as fixed factors and participant and "issue" as random factors. Clearly pointing out that most people *do not* completely switch their beliefs after a brief scientific communication was presented to them in an online study, the binary value of their previous belief was by far the strongest factor ($\beta = 1.51$, 95% CI [1.37, 1.64], $p < 0.001$). As predicted, scores in science's epistemology had a positive and statistically significant effect ($\beta = 0.18$, 95% CI [0.07, 0.29], $p = 0.002$) replicating our previous finding. Degree of education ($\beta = 0.07$, 95% CI [−0.15, 0.29], $p = 0.54$) and age ($\beta = -0.03$, 95% CI [−0.14, 0.08], $p = 0.58$) appeared as non-statistically significant factors in contrast, while gender (female) was statistically significant and positive ($\beta = 0.24$, 95% CI [0.03, 0.45], $p = 0.025$). Introducing myside bias further enhanced the predictive power of the model while keeping the effect of science's epistemology robust (S.I. table 3.4).

4.2.3 Support for Belief Updating

We also replicated our previous result showing that a greater understanding of science's epistemology predicts stronger support for the norm of belief updating following both ideologically congruent and incongruent scientific results. The effect was statistically significant and positive ($\beta = 0.11$, $t(2763) = 3.01$, $p = 0.003$), and was unaffected ($t(2760) = 3.02$, $p = 0.003$) by the inclusion of demographic covariates (i.e., gender, age, and higher education degree), confirming that epistemological literacy predicts unique variance. Importantly, the effect proved to be robust after the inclusion of myside's ideological incongruence, itself a negative predictor ($\beta = -0.26$, $t(2651) = -10.49$, $p < 0.001$, S.I. table 3.5). A small, marginally significant interactive effect between higher epistemological scores and mysideness was also found ($\beta = -0.05$, 95% CI [−0.06, −0.00], $t(2650) = -2.04$, $p = 0.04$). This kept the positive additive effect of epistemological literacy largely intact ($\beta = 0.11$, $t(2650) = 2.71$, $p = 0.01$). Replicating the result of our previous study, embracing the norm of updating one's beliefs following the communication of specific scientific results was itself a strong predictor of switching one's beliefs to embrace the scientifically communicated results ($z = 8.71$, $\beta = 0.49$, $p < 0.001$, supplementary information 3.6). At the level of support for policymakers implementing the recommendations emanating from the presented scientific results, this time, the positive link between understanding of science's epistemology and support for policy implementation following the scientific results failed to replicate ($\beta = 0.05$, $t(2763) = 1.31$, $p = 0.19$). Moreover, a negative interactive effect emerged this time between science's epistemology and myside bias ($\beta = -0.06$, $t(2763) = -2.83$, $p < 0.01$), suggesting decreased enthusiasm for supporting evidence-based policy recommendations when the science was incongruent with one's ideological position.

4.2.4 Epistemology of Science and Increased Skepticism of Pseudoscience

Knowledge of science epistemology was clearly linked to an increased skepticism (diminished acceptance $r = -0.31$, 95% CI [−0.38, −0.24], $p < 0.001$) of pseudoscientific claims (α = 0.76). This latter finding replicates a result previously obtained in our pilot study to calibrate our survey instrument. Significantly, when controlling for education level in a linear model estimated using OLS, it is familiarity with the principles of scientific epistemology ($\beta = -0.63$, 95% CI [− 0.78, − 0.48], $t(689) = -8.39$, $p < 0.001$)—rather than education level itself ($\beta = 0.02$, 95% CI [− 0.11, 0.14], $t(689) = 0.26$, $p = 0.79$)—that predicts the rejection of pseudoscientific claims, as shown in Fig. 1.

4.2.5 Do the More Highly Educated Hold More Polarized Perceptions?

When we compared participants' initial beliefs regarding the fact of the matter for each one of the issues with an ideological central value, ideological extremity was found to be a clear positive predictor of how much their responses deviated from that hypothetical central response ($\beta = 0.13$, 95% CI [0.09, 0.17], $t(2651) = 6.26$, $p < 0.001$), but we failed to find statistically significant effects neither of science's epistemology ($\beta = 0.03$, 95% CI [− 0.08, 0.13], $t(2651) = 0.48$, $p = 0.63$) nor of educational level ($\beta = 0.00$, 95% CI [− 0.08, 0.09], $t(2651) = 0.21$, $p = 0.83$) thus replicating our previous result in the exploratory study. This time an interaction effect was found between ideological extremity and epistemological literacy ($\beta = 0.06$, 95% CI [0.02, 0.10]), $t(2650) = 2.95$, $p = 0.003$). That effect showed up both on the initial beliefs and, in slightly diminished form, on the beliefs reported after reading the pieces of scientific communication ($\beta = 0.05$, 95% CI [0.01, 0.09], $t(2650) = 2.64$, $p = 0.01$). Nevertheless, there was no interaction as such between mysideness (ideological incongruence) and epistemological literacy ($\beta = -0.02$, $t(2650) = -1.17$, $p = 0.24$), and closer inspection revealed that responses concerning the economic effects of immigration were primarily responsible for the observed interaction, in this case an important split appearing between the epistemologically literate on the far left side

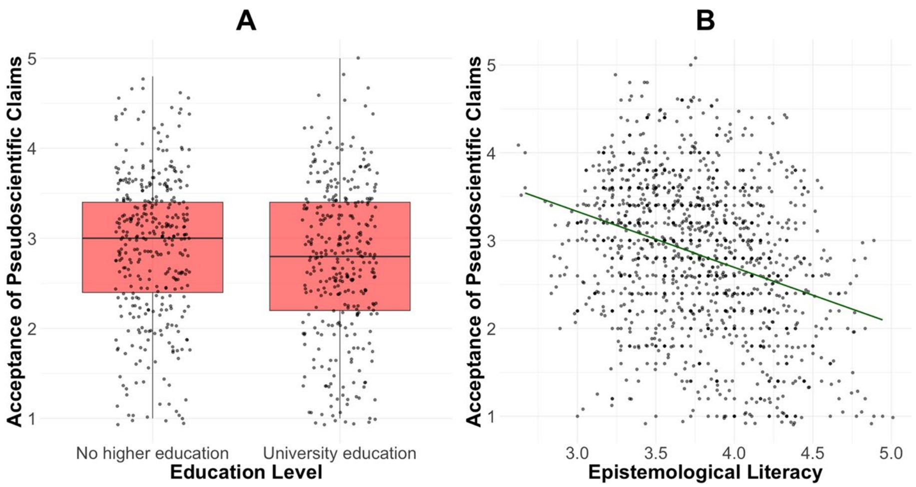

Fig. 1 Comparison of education level and epistemological literacy on acceptance of pseudoscientific claims. The figure contrasts the impact of educational level and epistemological literacy on the acceptance of pseudoscientific claims. **A** Boxplot comparing the acceptance of pseudoscientific claims between participants with no higher education and those with a university education. **B** Scatter plot showing the negative linear relationship between epistemological literacy and acceptance of pseudoscientific claims

of the political spectrum and the rest.[4] A further check testing the interactive effects of epistemological sophistication and myside bias on perceptions of the scientific consensus yielded that an increased understanding of science's epistemology did not lead to more polarized beliefs but in fact to a statistically significant ($t(2660) = 4.40$, $p < 0.001$) increased acceptance of the communicated scientific consensus.

5 Pre-registered 9-Week Follow-Up Survey

Would the effect brought about on beliefs on contentious issues by the simple reading of a brief scientific communication have some endurance and still be noticeable months later? We were interested in studying the persistence of the observed effects over time. A deflationary interpretation would suggest that it would not, and the effect observed right after the participants read the scientific communication would disappear once they went back to their lives as usual. A more sanguine hypothesis would underscore how sensitivity to science's epistemology might actually be a facilitator of belief change following science, not only in a passing way. We wanted to find out, and thus, we asked the survey company to recontact participants who had completed our survey.

5.1 Methods

5.1.1 Participants

Panelists at the IMOP national online panel who had first completed our previous survey were invited to participate in one further study 9 weeks after we closed our previous questionnaire. The invitation to this second wave of measurement was closed 3 weeks later. That means that participants could re-enter our study in this second stage between 2 and 3 months after they first read the four different scientific communications.

5.1.2 Beliefs After Two Months

As they entered the study, participants were asked again their view on the facts of the matter for each of the four questions (global warming, nuclear safety, economic effects of immigration, rent control). As in our two previous studies, participants' responses were recorded as such but also transformed into a binary variable for each issue, reflecting whether the participant had a belief contrary to/in accordance with the scientific results communicated in the first wave of the survey. This initial question on their views was *not* accompanied by any reminder of the content of the scientific communication 2 months earlier.

[4] The great divergence on views on immigration was not between those high in epistemological literacy on the right and those high in epistemological literacy on the left. Comparing immigration responses by extreme quartile groups revealed that those on the far left tended to deviate more from the central response of the population both before and after being presented with the scientific results, with the difference being greater compared to participants with low science epistemology understanding on the far right (before diff. = 1.79, CI [1.07 2.51], $p < .001$; after diff. = 2.19, CI [1.38 2.99], $p < .001$) but smaller compared to those also scoring high in epistemology on the other side of the political spectrum (before diff. = 1.00; after diff. = 1.35). See Salvadori et al. (2022) for contrasting data on immigration, polarization, and cognitive sophistication.

5.1.3 Perception of Consensus and Epistemic Vice

On the next screen, participants were questioned about their perception of the degree of scientific consensus (*slider item from 0 to 100%*) on the scientific results which were this time presented in a synthetic one-sentence form to remind them. They were also asked to report their degree of agreement or disagreement with two statements conceived to measure their perception of epistemic vice or epistemic mistrust in relation to the community of researchers behind those results.

5.1.4 LSESI and Demographics

Before exiting the survey, participants were asked to fill out the 18-item Lay Science's Epistemology Survey Instrument, report their last educational degree obtained, and provide their political self-identification, with a chance to opt out of the question if they so desired. Variables and main analyses were pre-registered at the as.predicted platform.

5.2 Results

A total of 858 participants completed this survey, of which 791 passed the two attention checks scattered between the different questions. Due to the non-negligible number of participants who were excluded from the analysis of the previous survey wave, our final linked survey file with exclusions had 572 participants in total who had passed all the attention checks and responded correctly to all the different comprehension questions presented in the first and second wave of the survey (50% female, $M_{\text{age}}=45.6$, 53% left-wingers, 25% right-wingers, 18% centrists).

5.2.1 Pre-registered Confirmatory Test

Extending our previous findings, the effect of the lay understanding of science's epistemology on embracing the opinion aligned with the communicated scientific consensus proved to be both statistically significant and positive ($\beta=0.13$, 95% CI [0.03, 0.22], $p=0.011$; see also Fig. 2). Comparing the previous model with a model now including age, gender, and university education, the new model did not seem to explain more variance; none of the demographic variables reached the threshold of statistical significance, and the effect of science's epistemology was still positive and statistically significant ($\beta=0.12$, $p=0.022$). In a further step, the inclusion of mysideness (ideological incongruence) enhanced the explanatory power of the model (showing an improvement in the pseudo-R^2 for fixed effects from 0.21 to 0.25). When it came to reversing the beliefs toward the scientifically communicated results, myside's incongruence proved to be both negative and statistically significant ($\beta= -0.42$, 95% CI [$-0.53, -0.31$], $p<0.001$). The effect of an enhanced understanding of science's epistemology was still statistically significant and positive ($\beta=0.13$, 95% CI [0.03, 0.24], $p=0.01$), thus prompting the conclusion that a more adjusted view of the knowledge-generating process behind scientific research eases the adoption of science-based beliefs even 2 months after those views were presented.

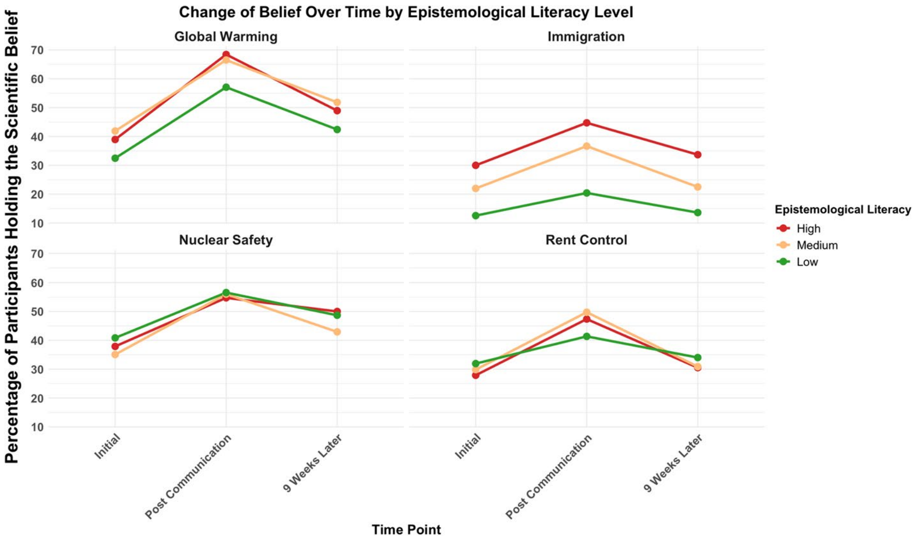

Fig. 2 Change of belief over time by epistemological literacy level. The figure shows the percentage of participants holding the communicated scientific belief at three different time points (initial, post-communication, 9 weeks later) across four controversial issues (global warming, immigration, nuclear safety, rent control)

5.2.2 Further Exploratory Results

Epistemic Mistrust and Epistemological Literacy Epistemic mistrust, in the form of attribution of epistemic vice to specific communities of scientists, was perhaps the largest factor in accounting for the ideological assortment of attitudes among the variables that we measured. Interestingly, epistemological literacy clearly diminishes attributions of epistemic vice. When we explored the general effects of epistemological literacy on attribution of epistemic vice toward the scientific communities producing ideologically incongruent results, *mysideness* ($\beta=0.22$; $t(2186)=9.12$, $p=<0.001$) and *epistemological literacy* ($\beta=-0.31$; $t(2186)=-6.74$, $p=<0.001$) had neat, respectively, positive and negative, divergent effects explaining the public's attribution of epistemic vice, effects which in this case were partly attenuated by a clearly smaller interaction ($\beta=0.06$; $t(2186)=2.82$, $p=0.005$). We replicated our analyses to see whether education or understanding of science's epistemology could be aggravating factors in accounting for the polarization of beliefs following ideological commitments. Reproducing our multilevel model with the new data, again, we could not find any additive effect neither of epistemological literacy ($\beta=0.02$, $t(2200)=1.05$, $p=0.29$) nor of the degree of education on increased divergence from the ideological central value ($\beta=-0.06$, $t(2200)=-1.21$, $p=0.23$). As in our second, but not our first, study, we observed a small interactive effect between ideological extremity and epistemological literacy ($\beta=0.05$, $t(2200)=2.28$, $p=0.02$).[5] Supporting our general interpretation of the effects of epistemological sophistication and ideological incongruence, an

[5] As in the previous wave, closer inspection suggested that for the most part, the interaction effect was driven by a split found mainly between high epistemological literacy participants on the left and the rest (most notably low epistemological literacy on the right) on the issue of immigration.

analysis of how epistemological literacy explains the public's representation of scientific consensus yielded that mysideness ($\beta = -3.25$; $t(2189) = -8.42$, $p = <0.001$) and epistemological literacy ($\beta = 1.89$; $t(2189) = 3.75$, $p = <0.001$) had diverging, respectively, negative and positive effects when accounting for the public's acknowledgment of scientific consensus. A smaller negative interaction between the two did appear ($\beta = -0.74$; $t(2189) = -2.11$, $p = 0.03$) suggesting an average attenuated effect of epistemological literacy on perceptions of scientific consensus when one's ideological position is more at odds with it. While specific cases may reveal nuanced sociological distinctions between some of the socioscientific controversies at play, it appears that the influence of myside bias and epistemological literacy on embracing science-based beliefs diverges significantly (Fig. 3).

5.2.3 General Discussion

More than 9 weeks after having received a short piece of science communication on ideologically congruent and incongruent results, a greater understanding of science's epistemology predicted change of opinion, higher scores on the Lay Science's Epistemology Survey Instrument indicating greater odds of embracing a belief in line with the scientific results. In addition, an understanding of science's epistemology also was linked with diminished epistemic mistrust toward the scientific community responsible for ideologically incongruent scientific results, a specific form of epistemic mistrust that is perhaps the largest explanatory factor behind ideologically motivated science denial.

In the literature on Bayesian rationality, a line of argument vindicates how it sometimes makes sense to use discrepancies between one's prior beliefs and the priors of other epistemic agents to discount the diagnostic value of contrarian evidence (O'Connor & Weatherall, 2018; Stanovich, 2021). It also stands out that such locally rational heuristics might lead to globally pernicious effects. Thus, for certain controversial issues, scientific communication might sometimes increase, not decrease, polarization, and at the extremes, the virtuous consensus-reaching process sometimes termed Baconian convergence (Strevens, 2020) can be conspicuous by its absence (Michelini et al., 2023). In contrast, our study found that a greater understanding of science's epistemology seemed to be linked with both lower epistemic mistrust of scientific communities promoting ideologically incongruent results as well as a higher predisposition to accept scientific consensus.

Several qualifications still apply. As revealed by some of our analyses, intensification effects involving cognitive sophistication can sometimes be obtained, the general effect of epistemological literacy being sufficiently heterogeneous for different issues and at different levels of ideological extremity to consider the "conflict of interest hypothesis" a live possibility (as documented for certain issues among the US public). In addition, since the importance that participants give to the issues might not always be perfectly correlated with their ideological positions (Viciana et al., 2019), one possible shortcoming of our study could in principle be linked to our measuring of ideological incongruity as a proxy for mysideness. Could it be the case that citizens with a more sophisticated understanding of science do not tend to associate their identities so strongly with empirical questions that can reasonably be in dispute (Galef, 2021)? We did not test for this interesting possibility. In addition, it is a well-known fact that surveys are sometimes subject to certain forms of expressive responding in which ideology trumps sincerity in the responses. Under a deflationary account, partisans and

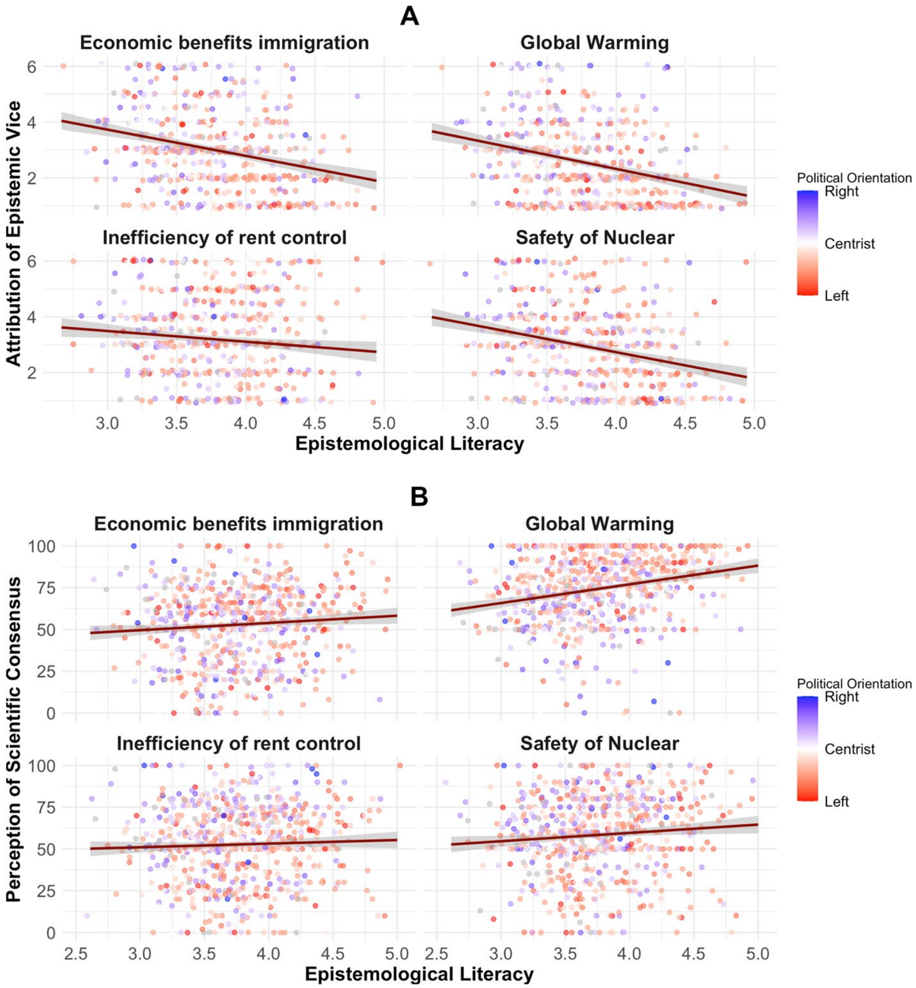

Fig. 3 Attributions of epistemic vice and perceptions of scientific consensus: effects of epistemological literacy and political orientation. The figure illustrates the relationship between epistemological literacy and political orientation on the attribution of epistemic vice (**A**) and perception of scientific consensus (**B**) across four controversial issues (economic benefits of immigration, global warming, inefficiency of rent control, safety of nuclear). Data points have been slightly jittered to ease visualization

ideologues are motivated to support the beliefs of their team and not to respond to what they "truly believe" (Malka & Adelman, 2022). Were we to accept this as a possible limitation of our study, our findings would still apply, but an interesting question would then be whether and why participants who are more attuned to how scientific practices generate knowledge would show fewer signs of ideological expressive responding in the context of reading and commenting on scientific results on hotly contested issues.

6 Conclusions

In recent years, perhaps as a result of the exaggerated perception of certain trends, an overly catastrophic vision has suggested that we now live in the post-truth era. It is sometimes difficult not to be indulgent toward this diagnosis. Indeed, echoing previous investigations, in our study, citizens were less likely to update their views in the direction of scientific evidence when it was inconsistent with their ideological views. And yet, contrary to other previous studies, we did not find that education level or greater familiarity with science were the culprits. Rather, our findings are congruent with similar recent research (Fischer et al., 2022; Pennycook et al., 2023), which might prompt a reassessment of the background model of the cognitive factors and sociological forces at work when connecting educational level and polarization dynamics.

One question that naturally arises is why familiarity with the epistemology of science would play this role in relation to updating one's beliefs with regard to controversial issues. The question may be all the more pressing as we truly attempt to strip our science's epistemology measure of items that would directly reflect confidence in scientific institutions. One possibility, highlighted by several authors, arises from the fact that partisans and so-called merchants of doubt tend to use a biased perception of the epistemology of science to advance their denialist objectives (Kovaka, 2021; Staley, 2019). Under this view, a better understanding of the processes ensuring trust in scientific results could preempt the spread of these ideas. Perhaps, it defends us from jumping to the conclusion that "true" scientific knowledge can only be in the form of absolute facts or that uncomfortable findings are anchored in an invalidating form of subjectiveness through the prejudices of degenerate scientific communities (Hannikainen, 2019). Additionally, it has sometimes been remarked how our understanding of what knowledge is tends to develop from a more primitive stage in which absolutist views are embraced (e.g., true knowledge as a direct reflection or "mirror of reality") toward a more elaborate view, in which knowledge-seeking is seen as an open process that can be improved to the extent that the parts bringing considerations to the debate ascend in the ladder of evidence (Barzilai & Chinn, 2018). Indeed a few items included in our Lay Science's Epistemology Survey Instrument expressed allegiance to the view that disagreements on matters of fact can be resolved by an appeal to better scientific evidence. It has also been pointed out how epistemological literacy tends to involve a greater understanding of the nature of scientific uncertainty and a better grasp of the processes that ensure different degrees of confidence in scientific results (Kampourakis & McCain, 2020). A view which was also corroborated during the development of our Lay Science's Epistemology Survey Instrument. Thus, holding a more accurate view of the nature of scientific knowledge could provide some amount of immunization against the strategic exploitation of uncertainty and scientific dissent. Yet another possibility goes back to the heuristic of being suspicious of the testimony of new sources when their approaches are far removed from our own, and we also lack contextual information to support their reliability. Perhaps, individuals with an understanding of the epistemology of science are also more sensitive to cues that indicate a good track record of reliability, this idea being a promising avenue for future exploration.

In examining the intricacies of specific socioscientific controversies such as those surrounding vaccines, climate change, immigration effects, or nuclear energy safety, the local dynamics of trust and distrust toward scientists emerge as big pivotal factors. While an enhanced comprehension of science's epistemology may seem secondary, its potential for fostering greater public trust in science warrants consideration. Could enhancing the epistemological understanding of science among lay individuals offer some form of cross-protection in the face of pseudoscience and science denialism? We believe so.

Tribal denialist beliefs often include a memetic component, which helps them survive and spread by fostering distrust, especially when there are no countervailing forces. A better grasp of the hierarchy of evidence, scientific uncertainty, and familiarity with the scientific process behind the critical scrutiny of results could confer some amount of "broad-spectrum" immunity against bias. As recent simulations on the social effects of immunization against misinformation show, the pull of biased beliefs can be restrained as soon as a fraction of the population is sensitized to misinformation cues (Pilditch et al., 2022). In this fashion, expanding the percentage of the population that embraces a more accurate view of the way that scientific consensus tends to form holds promise as a way of safeguarding against widespread diffusion of the worst kinds of science denial.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Informed Consent All participants provided informed consent prior to their inclusion in the study.

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